SENSORIMOTOR TESTING FOR THE EARLY IDENTIFICATION OF INDIVIDUALS AT RISK OF DEVELOPING CARPAL TUNNEL SYNDROME

by

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ABSTRACT

Carpal tunnel syndrome (CTS) is one of the most common injuries responsible for lost time claims to the Workplace Safety and Insurance Board (WSIB). The main purpose of this study was to determine whether measurable sensorimotor changes exist in asymptomatic individuals who are at risk for CTS such that sensory impairment and/or functional tests may be used in the early detection and intervention to reduce the impact of CTS on individuals, industry and the health care system. Participants were recruited into three strata: (1) individuals diagnosed with mild CTS, (2) asymptomatic individuals who were deemed to be at risk of developing CTS due to exposure to etiological risk factors and (3) asymptomatic individuals who were deemed to be at minimal risk of developing CTS based on non-exposure to risk factors. The main outcome measures included two-point discrimination ability, pressure acuity, vibration sense, Purdue Pegboard Test performance and tracking error and tracking variance on a manual tracking task performed at two different speeds. Seven individuals with CTS, fourteen individuals at risk of developing CTS and nine control individuals with minimal risk participated. The CTS group was significantly different from the at-risk and control groups on the main and work sections of the DASH questionnaire, and the symptom severity scale and functional status scale of the Boston Carpal Tunnel Questionnaire. The only outcome measure that showed a significant difference between the at-risk and the minimal risk group was the assembly task of the Purdue Pegboard Test \( p = 0.044 \), however other measures including median nerve conduction latencies, and manual tracking abilities showed promise that with further recruitment, a significant difference may be seen. The sensory impairment tests did not demonstrate degradation in sensory function in individuals at risk of developing CTS, however analysis of sensory nerve conduction latencies and some aspects of fine motor skills testing did show some promise in their ability to detect individuals at risk of developing CTS. A future prospective study that follows individuals at risk
of developing CTS may determine that it is possible to implement a screening tool for the early identification and treatment of CTS.
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LIST OF ABBREVIATIONS

CTS: Carpal Tunnel Syndrome

WSIB: Workplace Safety and Insurance Board

DASH questionnaire: Disability of the Arm Shoulder and Hand Questionnaire

SSS: Symptom Severity Scale (aspect of the Boston carpal tunnel questionnaire)

FSS: Functional Status Scale (aspect of the Boston carpal tunnel questionnaire)

CMAP: Compound Muscle Action Potential

SNAP: Sensory Nerve Action Potential

CNAP: Compound Nerve Action Potential

CAD: Computer Assisted Design

NCS: Nerve Conduction Study

CCT: Carpal Compression Test

NSAID: Non-steroidal Anti-inflammatory Drug

RSI: Repetitive Strain Injury

EMG: Electromyography

APB: Abductor Pollicis Brevis

RMS: Root Mean Square

ANOVA: Analysis of Variance

SD: Standard Deviation
Chapter 1

INTRODUCTION

1.1 BACKGROUND

Carpal tunnel syndrome (CTS) is a sensorimotor peripheral nerve condition caused by localized compression of the median nerve as it crosses the wrist within the carpal tunnel, and often results from work-related activities. CTS is reported to be the most common peripheral nerve disorder seen in the working-age population (Atroshi et al. 1999), and is more prevalent in women (De Krom et al. 1992). In 2007, 723 (0.9%) of the 80,863 lost time claims processed through the Workplace Safety and Insurance Board of Ontario (WSIB) were due to CTS. With an average cost of $24,133 paid out per lost time claim, individuals who required time off of work due to CTS cost industry approximately $17.5 million (WSIB, 2007). Although the total number of claims has been decreasing since 2003 (Table 1.1), the percentage of those claims which are due to CTS remains relatively consistent at around 1%, and CTS continues to be the tenth most common claim (tied in 2007, out of over 50 different diagnoses). These data do not include claims by individuals who did not require time off work, or cases that went unreported, and as such they can be considered to underestimate the total number of CTS claims and their financial impact. These data are from the Statistical Supplement to the 2007 Annual Report of the WSIB of Ontario.
Table 1.1: Lost time claims for carpal tunnel syndrome from 2003 to 2007, and as a percentage of the total lost time claims to the WSIB of Ontario.

<table>
<thead>
<tr>
<th>Year of injury</th>
<th>2003</th>
<th>%</th>
<th>2004</th>
<th>%</th>
<th>2005</th>
<th>%</th>
<th>2006</th>
<th>%</th>
<th>2007</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTS</td>
<td>945</td>
<td>1.0</td>
<td>867</td>
<td>1.0</td>
<td>859</td>
<td>1.0</td>
<td>815</td>
<td>1.0</td>
<td>723</td>
<td>0.9</td>
</tr>
<tr>
<td>Total</td>
<td>93,234</td>
<td>100</td>
<td>90,397</td>
<td>100</td>
<td>89,734</td>
<td>100</td>
<td>83,179</td>
<td>100</td>
<td>80,863</td>
<td>100</td>
</tr>
</tbody>
</table>
CTS is especially common in workers who perform repetitive wrist and hand activities, such as dental hygienists, computer assisted design (CAD) designers, and data input personnel (Garland et al. 1996). In addition to physical impairment and pain, CTS has negative financial consequences for workers, including lost income due to time away from work and ancillary medical expenses (Pascarelli and Quilter, 1994).

Individuals with CTS present with a number of symptoms including pain, numbness and/or paraesthesias in the sensory distribution of the median nerve (i.e. the thumb, index, and middle fingers and sometimes the radial side of the ring finger). CTS is characterized by numbness, tingling, burning, or pain in at least one of digits 1, 2, or 3, with other symptoms including palmar pain, wrist pain, or radiation of pain proximal to the wrist joint (Franklin et al. 2007). Wrist pain, digital weakness, an inability to pinch strongly and the frequent dropping of objects are also common complaints, particularly when the condition has progressed to later stages (Preston and Shapiro, 1998). These signs and symptoms can severely impede an individual’s ability to proficiently complete their work tasks, particularly if the work requires fine motor skills or a strong grip.

Prevention strategies have proven to be an effective way of reducing the occurrence of injuries in other musculoskeletal disorders, such as low back pain in nurses (Collins et al. 2004; Trinkoff et al. 2003), and should presumably also be effective for CTS, however to date, early diagnosis and intervention programs to prevent CTS do not exist. Despite the development and marketing of myriad “ergonomic” products for computer and other workstations, the incidence and prevalence of CTS remains relatively constant. Screening capable of identifying individuals who are imminently at risk of developing CTS, but who are still asymptomatic could be beneficial in that targeted prevention, and management strategies could be implemented before
the worker’s condition progresses and he or she develops CTS with resultant loss of productivity, lost work time, worker retraining and the need for disability premiums to be paid out.

The purpose of this study was to determine if there are pre-symptomatic sensory, motor or electrophysiological signs of CTS evident in individuals at risk of developing the condition, compared with those who are not at risk.
Chapter 2

LITERATURE REVIEW

2.1 ANATOMY OF THE WRIST JOINT

The motor branches of the median nerve innervate most of the muscles of the anterior forearm and lateral palm, including five intrinsic muscles of the hand and the thenar muscles that are used to adduct and oppose the thumb. The sensory or cutaneous branches innervate the skin of the lateral two thirds of the hand and the dorsum of digits 2 and 3. The lateral two thirds includes digits 1-3, as well as the radial portion of digit 4. As it crosses the wrist joint, the median nerve runs under a ligamentous band called the flexor retinaculum or the transverse carpal ligament, which forms an anteriorly concave tunnel, known as the carpal tunnel. The carpal bones (hamate, pisiform, triquetrum, lunate, capitate, scaphoid, trapezium, and trapezoid) form the lateral and posterior borders of this tunnel. The median nerve shares the space within the carpal tunnel with many long tendons which extend from the forearm to the fingers. Sharing this confined space makes the median nerve particularly susceptible to injury as inflammation of any element within the carpal tunnel, such as tendon swelling or thickening resulting from overuse, can compress the nerve (Marieb and Mallatt, 1997).

2.2 ETIOLOGY OF CTS

2.2.1 OCCUPATIONAL FACTORS

Over the past two decades CTS has been a prominent occupational disease, serving as a basis for many workers’ compensation claims (Kao, 2003). The results of many studies have implicated certain occupational tasks as contributing to the development of CTS. The factors which have been most widely accepted as occupational hazards in the development of CTS
include repetitive or sustained flexion of the wrist or contraction of the muscles whose tendons pass through the carpal tunnel, especially when doing forceful work (Zakaria et al. 2002; Palmer et al. 2007; WSIB, 2008). This type of work has been found to cause inflammation of tendons which can alter the space within the carpal tunnel, and to apply external pressure and thus compress the median nerve (Zakaria et al. 2002). Vibration and mechanical pressure have also been associated with an increased risk of developing CTS (Zakaria et al. 2002; Palmer et al. 2007; WSIB, 2008). Awkward postures at the wrist can increase pressure in the carpal tunnel, or directly compress the median nerve, which may lead to the development of CTS (Zakaria et al. 2002).

2.2.2 NON-OCCUPATIONAL FACTORS

There are a variety of non-occupational factors that contribute to the risk of developing CTS. These factors can be divided into intrinsic and extrinsic factors. Intrinsic factors are those which occur within the carpal tunnel itself, such as pressure increases due to space reduction or fluid accumulation, which in turn can lead to compression of the median nerve. Examples of these intrinsic factors include inflammatory conditions such as rheumatoid arthritis, metabolic conditions such as diabetes mellitus, and the use of certain medications including insulin, sulphonylureas, metformin or thyroxine (Geoghegan et al. 2004). Corticosteroid use, even in the absence of arthritis, has also been cited as a risk factor for CTS (Solomon et al. 1999). In women, retention of fluids due to pregnancy, as well as estrogen replacement therapy are also thought to increase the risk of developing CTS (Solomon et al. 1999; Tupković et al. 2007, Padua et al. 2001).

Extrinsic non-occupational factors are those which change the dimensions of the carpal tunnel. Major extrinsic factors include previous wrist fracture and osteoarthritis of the wrist and
carpus (Geoghegan et al. 2004). These conditions can reduce the space in the carpal tunnel which may cause crowding and the compression of the median nerve.

### 2.3 Diagnosis of CTS

There are two diagnostic techniques which are generally used to confirm a diagnosis of carpal tunnel syndrome: nerve conduction studies (NCSs) and clinical symptoms testing. A combination of the two techniques is commonly used, especially when surgery is being considered as a treatment option.

#### 2.3.1 Nerve Conduction Studies

Since CTS-like symptoms can be mimicked by lesions in any part of the nervous system, from the cerebral cortex to sites along the peripheral nerve, tests of nerve conduction through the carpal tunnel are important in the diagnosis of CTS, especially when the condition is in its milder stages (Stevens, 1997). Neurophysiologic data obtained in NCSs are generally recorded using surface electrodes for both stimulation and recording. Studies of motor, sensory or compound (mixed) nerve action potentials are used in the neurophysiologic diagnosis of CTS. Through transcutaneous electrical stimulation of a nerve, its conduction properties can be investigated by measuring certain characteristics of the resulting signal recorded at a site distal or proximal to the site of stimulation (Preston and Shapiro, 1998). Motor action potentials, known as compound muscle action potentials (CMAPs), are a summation of all of the fibers in the muscle transmitting action potentials as a result of motor nerve stimulation at some point proximal to the recording site on the muscle. Sensory and compound nerve action potential studies are generally done by stimulating and recording from a cutaneous site over the nerve. Sensory nerve action potentials (SNAPs) are recordings of the sum of action potentials traveling along a sensory nerve, and compound nerve action potentials (CNAPs) are a combination of the action potentials transmitted
SNAPs can be studied antidromically or orthodromically. Antidromic recording of sensory nerve conduction involves recording nerve conduction as action potentials travel towards the sensory receptors (i.e. stimulating at the wrist and placing the recording electrodes at the fingers) which is opposite the normal physiological direction of transmission along the sensory nerve, and orthodromic recording involves recording conduction in the direction of normal physiologic conduction (i.e. stimulating at a distal site such as the digits and recording the resultant sensory nerve signal at the wrist). Conduction occurs equally well in either direction, therefore both types of recordings are used in clinical evaluation. Evoked potential amplitudes are, however, generally higher when recording is performed antidromically because the electrodes are often closer to the nerve in this configuration. For example, when recording orthodromically by stimulating the digital sensory nerves, there is tissue between the median nerve and the skin surface thus a low-pass filtered version of the evoked potential signal is recorded. Antidromic stimulation is therefore more commonly used as it allows for the analysis of smaller potentials, which are less likely to be masked by noise or artifact (Preston and Shapiro, 1998). One disadvantage of antidromic recording is that, because of the proximity of the electrodes to nearby muscles, stimulation of motor nerves and muscles may also be picked up by the recording electrodes. This is generally not a major issue when studying the median nerve at the wrist as the SNAP occurs well before the motor activity, and is usually easily distinguishable from the conducted motor nerve action potential, which is smaller in amplitude at SNAP stimulation intensities (Lesser et al. 1995; Hennessey et al. 1994). CNAPs are mixed nerves which contain both afferent and efferent fibers and thus stimulation can not be classified as orthodromic or antidromic. CMAPs, on the other hand, can only be studied in the normal physiologic direction of nerve conduction. By stimulating the motor nerve proximally and
recording from the distal muscle, the resultant signal characteristics reflect the speed and patency of conduction of the signal along the motor nerve, the transmission across the neuromuscular junction, and along innervated muscle fibers (Preston and Shapiro, 1998).

SNAPs, CNAPs and CMAPs have four important measurable latency components that are used in electrophysiological studies. These measures include (a) the onset, which is the time after stimulation when the signal first rises above the baseline, (b) the time of the negative peak, which is the latency between the peak of the stimulus artifact and the peak of the first negative phase of the resulting waveform, (c) the time of the first baseline crossing, which occurs at the point where the phase of the evoked potential waveform first changes from negative to positive, and (d) the time of the positive peak, which is the latency between the peak of the stimulus artifact and the peak of the positive phase of the evoked potential waveform (Preston and Shapiro, 1998). Historically the waveform has been plotted such that the negative phase is represented above the baseline and the positive phase is represented below the baseline, as in Figure 2.1. The signal termination is also noted on Figure 2.1, however it is rarely used due to it being difficult to discriminate.
Figure 2.1: Outcome measures indicated on the CMAP waveform. Onset (circle), negative peak (square), baseline crossing (triangle), positive peak (diamond), and signal termination (rectangle) are denoted. Note that the end of the waveform is difficult to discriminate. SNAP and CNAP waveforms look similar to that of the CMAP.
Negative peak latency is the most commonly used outcome measure in SNAPs, and CNAPs (CMAPs use onset latency) due to the peak being an easily identifiable point of the evoked potential. There are published normative values for negative peak latencies recorded from the most commonly performed nerve conduction studies when stimulation is performed at standard distances from the recording site (Stevens, 1987), highlighting the need for consistency in the location of stimulation and recording electrodes when comparisons in latency are made between groups in research studies or when the tests are being used for diagnostic purposes.

Another important outcome measure is the amplitude of the evoked potential. Particularly when CMAPs are performed, a reduction in amplitude indicates that there is likely a neurophysiologic disorder causing muscle fiber or motor nerve conduction block or axonal loss (Preston and Shapiro, 1998).

The electrophysiologic criteria for diagnosing CTS can be found in section 3.4 in the Methods chapter.

2.3.2 CLINICAL SYMPTOMS TESTING

Clinical symptoms testing is the other category of tools commonly used for the diagnosis or classification of CTS. Symptom testing for CTS can be divided into three sub-categories: self-report tests, provocative symptom tests, and functional tests. Self-report tests include questionnaires probing the patient’s history, his/her functional abilities, as well as where and when symptoms are experienced. The Boston Carpal Tunnel Questionnaire, the Katz-Stirrat Hand Diagram and the Disability of the Arm, Shoulder and Hand (DASH) questionnaire are three main questionnaires used to classify CTS to gauge its severity, and to quantify its impact on functional abilities. The Boston Carpal Tunnel Questionnaire, which was developed by Levine et
al. (1993), combines a symptom severity scale (SSS) and a functional status scale (FSS) in which patients are asked a variety of questions about their symptoms and functional abilities (Levine et al. 1993). This questionnaire was found to be reproducible (Pearson correlation coefficient, $r = 0.91$ and $0.93$ for SSS and FSS respectively), coherent for the patient, valid (worse scores correlated with more severe impairment) and sensitive to clinical change and changes in patient satisfaction [correlations between satisfaction with the result of the operation and improvement in the scores were 0.50 for the SSS and 0.54 for the FSS (p < 0.01 for each)] (Levine et al. 1993).

The second commonly used questionnaire is the Katz-Stirrat Hand Diagram in which the patient is asked to mark the type and location of symptoms on a diagram of a hand (Katz and Stirrat, 1990). This questionnaire is most often used to confirm that the patient’s symptoms are consistent with the distribution of the median nerve. It was found to have a sensitivity of 80% and a specificity of 90% (Katz and Stirrat, 1990). The DASH questionnaire, which although not specifically designed for the wrist, can be used to evaluate the level of disability associated with a patient’s CTS (Boyd et al. 2005). The DASH questionnaire was introduced by the American Academy of Orthopedic Surgeons, along with other organizations for use as an evaluative outcome measure for patients or research subjects with upper extremity musculoskeletal conditions. It measures symptoms and functional status, with a focus on physical function (Hudak et al. 1996). High scores on the DASH correlate with more severe disability (Beaton et al. 2001). The DASH has been found to correlate well with other measures of upper limb disability, such as visual analog scales for function, pain and ability to work, as well as the Boston Carpal Tunnel Questionnaire ($r>0.69$). It is sensitive to change in disability before and after treatment (SRM, 0.74-0.8) and has high test-retest reliability (ICC$_{2,1} = 0.96$) (Beaton et al. 2001).
2.3.3 Provocative Symptoms Tests

Provocative symptom tests require the clinician to move the patients’ hands into positions, or apply pressure in ways that are known to be problematic in cases of CTS in order to determine whether or not these postures exacerbate their symptoms. The three widely used provocative clinical maneuvers are Phalen’s test, Tinel’s sign and the carpal compression test (CCT). Phalen’s wrist flexion test is the most commonly reported provocative test for CTS and is generally the most widely accepted (Priganc and Henry, 2003). For this test, the patient allows the wrists to fall into full flexion letting the fingers dangle downward. If a tingling sensation in the distribution of the median nerve starts in less than one minute, it is considered a positive sign for the presence of CTS (Phalen, 1966). Tinel’s sign involves tapping lightly directly over the location of the median nerve within the carpal tunnel proximal to the middle wrist crease. A tingling sensation radiating to the tip of the thumb or any of the first three fingers indicates the possibility of injury of the median nerve within the carpal tunnel (Tinel, 1915). The third commonly used provocative test is the CCT. This test is performed by pressing on the carpal tunnel, thus applying additional indirect pressure to the median nerve, for approximately 30 seconds to see if symptoms are exacerbated (Durkan, 1991). These provocative clinical tests, however, have been found not to be sensitive enough to diagnose or detect changes in CTS progression, with average sensitivities ranging from 50% to 68% for the three tests (MacDermid and Wessel, 2004; Priganc and Henry, 2003).

2.3.4 Impairment and Functional Tests

Impairment and functional tests examine a patient’s functional abilities when performing certain tasks that mimic daily activities, but are not normally performed when assessing CTS, and are therefore only discussed briefly here. Some of these tests are specific to the sensory
impairment of the median nerve, such as pressure acuity, two-point discrimination and vibration sense (MacDermid and Wessel, 2004). Other more functional tests require a combination of sensory and motor function such as the Purdue Pegboard Test (Irvine et al. 2004) that is widely used in functional upper extremity testing in patients with other neurological disorders. The Purdue Pegboard Test has seldom been used in the study of CTS, however it evaluates fine motor skills of the hand and its reliability has been well documented (Irvine et al. 2004), and therefore it may be useful in studying early sensory and/or neuromuscular changes. In 2001 Brouwer et al. (2001) introduced a manual tracking task that was capable of distinguishing between individuals with and without repetitive strain injuries of the upper extremity (including CTS), and therefore this test might also be of value in the early detection of sensory or neuromuscular disorders of the wrist. The sensory impairment and functional tests are described in detail in the methods section of this thesis.

2.4 MANAGEMENT OF CTS

Carpal tunnel syndrome may be treated with either surgery or with conservative management. Management decisions are based on, among other factors, the severity of the condition and the individual’s medical history. Conservative treatments for CTS usually consist of, (a) splints to limit the movement of the wrist and to maintain postures that are not harmful, (b) non-steroidal anti-inflammatory drugs (NSAIDs) or steroid injection into the carpal tunnel to reduce the inflammation that can compress the nerve, or (c) diuretics to cause a reduction in the amount of fluid within the carpal tunnel. These treatments are generally coupled with the modification of the individual’s activities (AAN, 1993, MacDermid and Wessel, 2007). Common surgical treatment of CTS includes open carpal tunnel release or endoscopic section of the transverse carpal ligament (Scholten et al. 2007). In severe cases of CTS, where there is motor
nerve involvement, surgical treatment is more effective than conservative treatment in relieving CTS symptoms (Verdugo et al. 2003; Gerritsen et al. 2002). Surgical intervention for CTS has been found to have success rates of up to 90% after 18 months, where success was defined as “completely recovered” or “much improved” (Gerritsen et al. 2002). The success rate for splinting was found to be 75%, however by the completion of the study, 41% of the original splinting group had received surgical carpal tunnel release (Gerritsen et al. 2002). A greater percentage of individuals in Gerritsen et al.’s study (2002) who underwent surgery reported complications and adverse affects than those who received conservative treatment, however the majority of these adverse affects were relatively mild and short lasting (Gerritsen et al. 2002). In a review including more than 8000 endoscopic surgeries, a success rate of greater than 90% was reported, with the definition of success varying between studies. The definitions of success included relief of symptoms, return to normal sensation, patient satisfaction, return to activities of daily living, and in one case, success was defined as renewed pinch and grip strength. With surgery there is a 2.67% complication rate and a 2.61% failure rate (Jimenez et al. 1998). Reported complications include de novo sensory disturbances, reflex sympathetic dystrophy, paraesthesias, pain or neurapraxia, and mild focal nerve lesions that result in localized conduction deficits without axon degeneration (Jimenez et al. 1998). In a retrospective questionnaire administered to 832 surgeons, who performed a total of 6833 operations for CTS, which were either open or endoscopic carpal tunnel releases, recurrent or persistent symptoms were found in 7.7% of open operations and 7.5% of endoscopic operations (Schneck, 1995). Such a failure rate may result in large economic and health impacts given the cost and prevalence estimates provided in the introduction.
2.5 Early detection of CTS

To date, there are no valid tests that can identify early (pre-clinical) signs of CTS. This means that often by the time CTS is diagnosed, the individual is already has discomfort and pain, and/or has had to take time off work; potentially having filed a workers’ compensation claim. If early markers of CTS can be identified in individuals at risk of developing CTS, then preventive strategies may be used to reduce or prevent the progression of the condition. From an economical standpoint, a procedure that is able to accurately detect pre-clinical signs of CTS may be beneficial to businesses if early and targeted interventions can reduce compensation premiums and lost productivity, may be beneficial to workers’ compensation boards by reducing their payouts, and may be beneficial to workers, by reducing the pain and associated disability that affects both their work-related and non-work activities.

Sensory deficits (e.g. numbness, tingling, burning, or pain) normally appear before motor deficits in individuals with CTS (Stevens, 1997). It was therefore assumed for the purposes of this study that early detection of individuals at heightened risk for CTS would most likely succeed if tests of sensory acuity and sensory nerve conduction were performed. If changes are evident, these changes are likely to resemble those seen in individuals who already have been diagnosed with CTS, however they will not be as marked. The following studies provide evidence to support this theory.

Gupta and Mahalanabis (2006) measured pinch strength, grip strength and two-point discrimination in workers at a shoe factory who performed repetitive motions and these measures were compared to those of a control group of hospital clerks who did not perform repetitive motions. Pinch strength and two-point discrimination were decreased in the at-risk group, whereas grip strength was not different between the groups. None of the subjects in the study
group were found to have a clinical diagnosis of CTS (Gupta and Mahalanabis, 2006). These results suggest that sensory function might be reduced prior to the development of CTS symptoms. The reduced pinch strength was likely reflects that the task specifically challenges the thenar muscles (opponens pollicis, adductor pollicis brevis) that are innervated by the median nerve.

Nerve conduction studies were performed by Bovenzi et al. (2000) on individuals whose occupations included the use of vibrating chainsaws over a five year period. The results were compared to age-matched workers who performed heavy manual work with no vibration as well as age-matched healthy control subjects, who did sedentary work that did not put them at risk for developing any sort of cumulative trauma disorder (Bovenzi et al. 2000). Slowed sensory nerve conduction velocities were found in the median and radial nerves of the workers who had been exposed to vibration, and nerve conduction velocities were also inversely proportional to daily exposure and lifetime use of vibrating tools. The vibration group and the heavy labor group both complained of pain or discomfort in at least one hand consistent with a cumulative trauma disorder at the time of testing, whereas the control group did not (Bovenzi et al. 2000).

Tremblay et al. (2002) compared grating (equally spaced grooves and bars on a block of wood) orientation discrimination, roughness discrimination as well as a test of dexterity between a group of frequent computer users and a group of occasional users (greater than or less than two hours of computer work respectively). They found that female frequent computer users performed significantly worse in the grating orientation task and the dexterity task (only the left hand showed significance but the right hand showed a trend towards decreased dexterity), but not the roughness discrimination task. These results were not seen in the males. Based on these results, it was expected that differences in the Purdue Pegboard Test and manual tracking tasks might
demonstrate differences between individuals at risk and those not at risk of developing CTS in the current study, but suggested that this difference may only be seen in females.

Only one study has compared sensory acuity between patients with a repetitive strain injury (RSI) (not limited to CTS) and asymptomatic individuals who were at risk for a RSI. Greening and Lynn (1998) analyzed vibration threshold using a constant frequency and varied amplitude (displacement) vibrometer. They tested the amplitude of vibration perception (going from low amplitude to high amplitude) as well as the loss of perception (going from high amplitude to low amplitude). Vibration threshold was significantly elevated in both the patient and at-risk groups when compared to a control group (Greening and Lynn, 1998).

Robinson and Kincaid (2004) compared two-point discrimination and pressure acuity between a control group and 10 string musicians who engaged in rapid, repetitive motions with their left hands. This study found no difference between the sensory perception of individuals who were at risk of developing CTS and those who were not, which highlights the possibility that early detection of these individuals may not be possible.

While the above studies provide insight into the possibility that early neurophysiologic changes may be seen in individuals at risk of developing CTS, there are currently no testing procedures that have been shown to be capable of identifying pre-symptomatic abnormalities suggestive of CTS and that might be of use in early identification.

2.6 STUDY OBJECTIVES

The purpose of this study was to determine if neurophysiologic differences were evident in asymptomatic individuals who work in occupations that are considered high risk for CTS. If such differences were detected, then these tests could potentially be used in the future to create a screening procedure capable of identifying individuals with pre-clinical signs of CTS before they
become symptomatic, thus potentially preventing the onset of the condition. Sensorimotor testing was used to compare a group of individuals who were deemed to be at risk of developing CTS to individuals who had mild CTS and to subjects who were deemed not to be at risk. Sensory function was determined using three tests: pressure acuity, two-point discrimination threshold, and vibration sense. These measures were expected to show reduced sensation in individuals at risk for CTS as compared to the control group. Further, it was expected that the deficits in the individuals at risk would resemble those observed in individuals with mild CTS. Two fine motor tasks were used to test functional abilities in the study: the Purdue Pegboard Test and a manual tracking task. Changes in fine motor function were expected to be evident in the CTS and the at-risk group but not in the control group due to the required integration of the impaired sensory and motor systems during these tasks.
3.1 Participants

Participants for this study were recruited into three groups: (1) individuals diagnosed with mild CTS, (2) asymptomatic individuals who were deemed to be at risk of developing CTS due to years of exposure to etiological risk factors and (3) asymptomatic individuals who were deemed to be at minimal risk of developing the condition (control group). For subject classification, CTS was defined as numbness, tingling, burning or pain in at least 1 of digits 1, 2, or 3 as well as confirmed electrophysiological deficiencies as described below (Franklin et al. 2007). Individuals with CTS were recruited from physiotherapy clinics in Kingston, Ontario using posters, as well as through referral from clinicians. They were also recruited using posters displayed in family physician offices in the Kingston area. CTS participants were only eligible if the condition was present in their dominant hand. This was in order to control for handedness. The at-risk and control individuals had their dominant hand tested in all cases. If CTS participants were tested in their non dominant hand, differences in performance may have been due to less well developed fine motor control in their non dominant hand instead of due to deficiencies caused by CTS. Individuals at risk for CTS were defined as those who performed repetitive or forceful tasks at the wrist in their occupation for greater than 5 hours a day and who had been doing so for a period of at least 5 years in order to ensure that they had been exposed to repetitive activity known to be associated with CTS, however all were asymptomatic. These thresholds were chosen arbitrarily in order to ensure that there was a distinct separation among the groups. In a related study (Tremblay et al. 2002) the authors divided the groups based on their spending greater than or less
than two hours on a computer per day. We chose a larger separation and higher computing times because we wanted to ensure that the separation between the groups was as evident as possible.

These individuals were recruited through distributing recruitment flyers to occupational sites in which individuals perform repetitive tasks known to place them at risk for developing CTS such as dental offices, ultrasound clinics, and administrators from businesses in the community. Control participants (those with minimal risk for CTS) were defined as those who did not perform repetitive tasks at the wrist in their occupation and used a computer for less than 2 hours per day, were asymptomatic and had no neurological deficits. These individuals were recruited from within the Kingston community, by posting flyers and advertisements and contacting eligible occupations such as nurses, occupational therapists and teachers (see Appendix B for recruitment posters). All control and at-risk participants were asked a series of questions prior to their participation to make sure they were eligible. Activities outside of work were also taken into consideration when determining the total amount of repetitive work performed by the individual. Control participants were sex and age matched (within two years) to at-risk individuals. CTS participants were not matched due to difficulty with subject recruitment. The proposed sample size was 20 subjects per group and was based on power calculations performed on published data. In order to observe 80% power to detect differences in two-point discrimination between groups, an n = 15 per group was required based on an effect size of 0.82 mm with a standard deviation of 0.76 mm (Jeng and Radwin, 1995). For the manual tracking task, n=19 per group was required based on an effect size of 1.1cm and a standard deviation of 1.15 cm (Violante et al. 2004). However, due to difficulties with participant recruitment only seven subjects were recruited for the CTS group, 14 were recruited for the at-risk group, and nine were recruited for the control group.
All participants were required to be between the ages of 18 and 60, as only adults were tested. The upper age limit was set because sensory and motor nerve conduction changes have been found in individuals older than 60, and these could have compromised the study outcomes (Lexell et al. 1983; McComas et al. 1993). In addition to deficits in nerve conduction, individuals older than 60 years of age also do not represent the working population that an early intervention program for CTS would target. Participants were excluded if they had ever had surgery (successful or unsuccessful) to treat CTS, had moderate or severe CTS as defined by motor deficits seen in the electrophysiologic exam, or had any history of neurological disorders, heart disease, lung disease or diabetes as determined by self report. This was done in order to avoid any confounding results and to avoid placing participants at any added risk. For example, an individual with a cardiac pacemaker would be at increased risk during the nerve conduction studies, due to the electrical stimulation, and individuals with neurological disorders may have demonstrated unexpected findings on their nerve conduction studies. Individuals with vision problems that were not corrected with lenses were also excluded, as some of the tests included in the protocol required visual feedback.

3.2 Protocol

After providing written informed consent (Appendix A) and filling out a demographic information form (Appendix C), all subjects completed the study protocol, which consisted of a brief physical examination, two questionnaires, a neurological exam, three tests of sensory impairment as well as two tests of fine motor skills. The tests were performed in the same fixed order for each subject. The protocol commenced with a clinical exam, which was performed by the investigator, that included Phalen’s test (Phalen, 1966), Tinel’s sign (Tinel, 1915), and a test for cervical radiculopathy (Magee, 2002). Both Phalen’s test and Tinel’s sign are described
above. The test for cervical radiculopathy required the participant to perform a series of movements including flexion, extension, lateral flexion, and rotation. If these motions did not exacerbate or relieve the individual’s symptoms, then the examiner added light axial pressure to the cervical spine by applying a downward pressure on the individual’s head. A positive indication of cervical radiculopathy was the exacerbation or relief of symptoms due to the movements of the participant’s head, the exacerbation of symptoms due to the axial pressure applied to the head, or the relief of symptoms associated with traction applied to the cervical spine through gentle lifting of the participants head. This evaluation was done first in order to reduce the potential impact of the functional tasks and nerve conduction studies on the results of the clinical tests. Next subjects underwent a test for two-point discrimination ability which was followed by the electrophysiology examination, a test for pressure acuity, the completion of the Disability of the Arm Shoulder and Hand (DASH) questionnaire, a test of manual tracking ability, the completion of the Boston Carpal Tunnel Questionnaire, which consists of the symptom severity scale (SSS) and the functional status scale (FSS), the Purdue Pegboard Test and finally a test of vibration sense. The order of the tests was arranged to separate the tests such that the impact of one test had minimal impact on the results of the next test. For example, the test for vibration sense was conducted last, as exposure to vibration has been shown to reduce an individual’s sensory acuity to touch and pressure for up to 25 minutes once the vibration has been removed (Thonnard et al. 1997; Bovenzi et al. 1997).

3.3 Questionnaires

The two questionnaires that were completed by the participants were used to gather descriptive demographic information: the Boston Carpal Tunnel Questionnaire and the DASH questionnaire (Appendix D). The Boston Carpal Tunnel Questionnaire (Levine et al. 1993)
consists of 11 questions regarding the presence and severity of the participants’ symptoms (SSS), including such information as provoking activities as well as intensity and duration of symptoms after provoking activities and eight questions regarding the difficulty the person has when performing everyday tasks such as writing, getting dressed or opening jars (FSS). The two are scored separately, and all of the questions are scored from 1 to 5, with 1 being the least severe and 5 being the most severe, and a mean score is reported for each section (Levine et al. 1993). That is, the overall score out of 5 for the SSS indicates the severity of the symptoms experienced by the individual and for the FSS indicates the overall difficulty the individual has with performing these every day tasks. In the original paper, Levine et al. (1993) reported that the questionnaire was effective for detecting condition changes pre- and post-operatively, a finding that was supported by Haybeli et al. (2003), making it an appropriate tool for audit or research purposes (Levine et al. 1993; Heybeli et al. 2003). Nashed (2008) confirmed that this scale separated individuals with CTS from control subjects (Nashed, 2008).

The main part of the DASH (Solway et al. 2002) consists of a 30-item scale measuring the disability and symptoms of the participant during the preceding week. The questions include information about the degree of difficulty in performing different physical activities, the severity of symptoms as well as the impact of the condition on quality of life. The outcome score is reported on a scale of 0 (no disability) to 100 (most severe disability) (Gummesson et al. 2003).

The outcome of these tests provided an indication of the presence of clinical symptoms and associated disability and was used in conjunction with nerve conduction studies to confirm study group assignment to the CTS group (presence of symptoms) or the at-risk/control group (lack of symptoms).
3.4 Neurological Examination

All participants underwent a series of nerve conduction studies which were used in conjunction with the questionnaire data to assess the presence of CTS. The results of this examination were also used as an outcome measure to compare those who were at risk to the other two groups.

Prior to the nerve conduction studies, the skin on the dominant hand was gently abraded with rubbing alcohol in order to decrease electrode-skin impedance and improve the adhesion of the electrodes. Monopolar surface electromyographic (EMG) signals were detected using the Neuroscan Comperio EMG system (Neuroscan Medical Systems, El Paso, Texas: bandpass of 5 Hz to 5 kHz, CMRR >100 dB at 60 Hz, Input impedance >100 mΩ) and self adhering Ag-AgCl electrocardiogram surface electrodes (Kendall-LTP, Chicopee, Massachusetts) cut in half to measure 1 cm by 3 cm in order to accommodate the small size of the recording area. A full sized electrode (2 cm by 3 cm) was used on the dorsum of the hand to act as the common reference.

Each participant was seated with their forearm supinated and resting on a pillow placed in their lap. A small amount of conductive gel was applied to the anode and cathode of the constant voltage stimulator prior to stimulation. Single pulse square wave stimulation with a duration of 100 µs was used to generate all evoked potentials. The stimulus amplitude was applied at 1 mA and was increased in approximately 5 mA increments until maximal SNAP, CNAP or CMAPs were detected. The stimulus amplitude was then increased by 20% to ensure that all axons were stimulated (Watson et al. 2006). An ensemble average of 10 responses was generated to improve the signal to noise ratios. The latencies of SNAPs and CNAPs were measured from the onset of the stimulus artifact to the negative peak of the waveform and the latencies of CMAPs were measured from the onset of the stimulus artifact to the onset of the waveform. CMAP amplitude
was measured using peak to peak amplitude (Stevens, 1997). The evoked potentials were performed on the median, radial and ulnar nerves in order for comparisons among nerves to be made and to rule out multiple nerve entrapment conditions. In addition, median nerve conduction velocity was determined at the antecubital fossa using the same recording electrode placements and providing stimulation just proximal to the antecubital fossa, in order to rule out median nerve entrapment at locations other than the carpal tunnel. Skin temperature was maintained constant for each individual during all neurophysiological testing, as temperature can affect nerve conduction velocities (Stetson et al. 1992). The following nerve conduction tests were used for subject stratification in addition to being an outcome measure to compare the at-risk group to the CTS and healthy control groups. A figure displaying the stimulation and recording placements for the nerve conduction tests can be found on page 29.

**SENSORY NERVE ACTION POTENTIAL**

**Median and ulnar SNAPs:** Median and ulnar nerve SNAP latency was measured antidromically, with the electrodes positioned over the proximal and distal interphalangeal joints of digit four. SNAPs were generated in both the median and ulnar nerve by stimulation at the wrist, 14 cm (15 cm on individuals with larger hands) proximal to the center of the negative electrode, which was the more proximal electrode (Stevens, 1997). The investigator then visually inspected the signal to ensure that a distinct onset, negative peak and positive peak were present. SNAP latencies of the median nerve were considered abnormal if there was a difference greater than 0.4 ms, when compared to the ulnar nerve on the same hand (Stevens, 1997). Stimulation was also applied to the median nerve at the antecubital fossa and latencies were recorded using the same electrode configuration. A
conduction velocity greater than 49 m/s was considered normal for this test (Preston and Shapiro, 1998).

**Radial nerve:** Radial nerve SNAP latencies were measured antidromically. The recording electrodes were placed distal to the anatomical ‘snuff box’ and at the metacarpophalangeal joint of digit one (Preston and Shapiro, 1998). The stimulation occurred at a distance of 10 cm proximal to the negative electrode (again, the more proximal electrode), along the radial nerve. A latency greater than 2.9 ms was considered abnormal and suggested that a radial neuropathy existed (Preston and Shapiro, 1998). Individuals with such findings were excluded from the study.

**Compound Nerve Action Potentials**

**Median and ulnar CNAPs:** Median and ulnar CNAPs were measured with electrodes placed over the respective nerve 8 cm proximal to the stimulation site at the radial and ulnar aspect of the palm respectively (Preston and Shapiro, 1998). The stimulation site was determined by drawing a line from the apex of the thumb, perpendicular to the main branch of the median nerve. This line indicated the halfway point between the two prongs of the stimulation probe for both the median and ulnar nerve. When the recording electrodes and stimulating probe were shifted to the ulnar nerve, the stimulator was moved along this line. The recording distance was determined by measuring proximally from the closest prong of the stimulation probe. CNAP latencies of the median nerve are considered abnormal if there is a difference greater than 0.4 ms, when compared to the ulnar nerve on the same hand (Stevens, 1997).
COMPOUND MUSCLE ACTION POTENTIAL

CMAP of the Abductor Pollicis Brevis from stimulation at the wrist: A median nerve generated CMAP was measured at the Abductor Pollicis Brevis (APB) following stimulation at the wrist. The active surface electrode was placed over the motor point of the APB, which is innervated by the median nerve, with the reference electrode located over the metacarpalphalangeal joint of the first digit (Preston and Shapiro, 1998). The motor point was determined by applying a low level repetitive stimulus to the muscle belly of the APB. The location which produced a visible muscle twitch with the lowest level of stimulus was considered to be the motor point. Onset latency and negative peak amplitude were measured for the CMAP. A latency greater than 4.6 ms and/or an amplitude below 4 µV with a CMAP was considered abnormal (Stevens, 1997).

CMAP of the Abductor Pollicis Brevis from stimulation at the antecubital fossa: The same electrode configuration was used as in the CMAP described above, however this time stimulation was done at the antecubital fossa, at the same location used for the SNAP recording. A conduction velocity greater than 49 m/s was considered normal and was used to rule out nerve entrapment in the forearm (Preston and Shapiro, 1998). Participants with evidence of nerve entrapment in the forearm were excluded from the study.
Figure 3.1: Stimulation and recording sites for a) SNAPS; ulnar nerve on the left of the first image, median nerve on the right of the first image and radial nerve on the right in the second image, b) CNAPs; ulnar nerve on the left and median nerve on the right, and c) CMAPs. The positive recording electrode (P), the negative recording electrode (N) and the point of application of the negative prong of the stimulating probe (S) are all displayed.
For all nerve conduction studies performed with the Comperio system, the software automatically placed markers on the evoked potential waveform indicating signal onset, negative peak, baseline crossing, positive peak, and signal termination. All markers were visually inspected by the investigator and adjusted if needed. From these markers the program calculated appropriate parameters such as onset latency, negative peak latency, negative peak amplitude and peak to peak amplitude.

3.5 Confirmation of Group Assignment

Participants were classified based on the presence of classic CTS symptoms as well as the results of the neurological examination. In order for a participant to be allocated into the CTS group, they were required to present with tingling, numbness, burning or pain in at least one of the first three digits, as well as have CTS confirmed by the nerve conduction studies. Confirmation of CTS required a prolongation of sensory nerve latencies (a prolongation of the median mid palmar CNAP greater than 0.4 ms relative to the ulnar mid palmar CNAP, or a prolongation of the median SNAP greater than 0.4 ms relative to the ulnar SNAP) (Preston and Shapiro, 1998; Stevens, 1997). If reduced CMAP amplitudes or increased CMAP latencies were seen, this suggested that the individual had CTS that was more severe and as such he or she was excluded from the study. Individuals who presented with CTS symptoms but no neurological deficiencies were excluded from the study. Individuals who were in the at-risk group presented with no symptoms of CTS, however they were not excluded from the study if they showed electrodiagnostic evidence of CTS. Therefore the results of the NCSs were also used as an outcome measure.
3.6 Functional Tests

3.6.1 Sensory Impairment Tests

Each individual who met the study inclusion criteria underwent three tests for sensory impairment: pressure acuity, two-point discrimination, and vibration sense. For all tests of sensation, the vision of the participant was occluded in order to prevent biases which may arise from the subject seeing the test being performed. Pressure acuity was tested using Touch-Test™ Sensory Evaluators (Semmes-Weinstein Monofilaments [SWMFs]) (North Coast Medical, Inc. Morgan Hill, California). The set of 20 fine filaments that bend at known pressures ranges from 0.008 g of pressure to 0.07 g of pressure (green – 4 filaments), 0.16 g of pressure to 0.4 g of pressure (blue – 2 filaments), 0.6 g of pressure to 2 g of pressure (purple – 4 filaments), and 4 g of pressure to 300.0 g of pressure (red – 10 filaments) are included in this set. All filaments are individually calibrated within a 5% standard deviation. A threshold in the green range represents normal sensation, the blue range represents diminished light touch, the purple range represents diminished protective sensation and the red range represents loss of protective sensation. As the mild CTS group was anticipated to have only mild sensory deficits, only the green, blue and purple filaments were used in this study.

The filaments were placed on the tip of digit two (MacDermid and Wessel, 2004) in a randomized order, and pressure was applied until the filament bowed. The participant was asked to verbally acknowledge when the pressure was felt. A lack of response indicated that the participant did not feel the stimulus. Each filament was administered 3 times (not necessarily in order as the order of application was randomized) separated only by the amount of time required to record the previous response, replace the old filament in the case and remove the new one. For those occasions when the same filament was applied back to back, the filament was replaced and
removed again so that the test subject would not know that the same filament was used. The lowest pressure filament where the participant reported feeling the pressure at least 2 of the 3 times for each filament was considered the outcome measure for pressure acuity.

Two-point discrimination was tested using a Disk-Criminator™ (Mackinnon-Dellon, Baltimore, Maryland). This tool contains two disks, each with a single prong and seven pairs of prongs which range in separation from 2 mm to 8 mm on one disk and 9 to 15 mm on the other. Only the smaller disk was used for this study. The pairs of prongs as well as the single prong were applied in a randomized order to the skin on the tip of digit two (MacDermid and Wessel, 2004), just until the skin turned white. As with the monofilaments, each pair was administered three times (not necessarily sequentially due to the randomization) with only the amount of time it took to record the previous response and rotate the disk to the new pair between applications. After each application, the subject was asked to determine if they were probed with a single prong or a pair. The outcome measure for this test was the smallest distance between prongs, in mm, that the subject could distinguish as two separate stimuli. A correct response given for 2 of the 3 applications of each pair was considered the overall positive, meaning that the participant could accurately sense two-point discrimination with that separation between prongs.

Vibration sense was measured using a LDS V200 series vibrator (Ling Dynamic Systems, Herts, England) attached to a BK Precision 3010 Function Generator (BK Precision, Yorba Linda, California) and ILP HY 50, 25 W amplifier (ILP electronics Ltd. Kent, England). The signal generator sent a signal of varying amplitudes and frequencies to the amplifier, which attenuated the signal, as well as to a computer which read the precise amplitude and frequency of the signal. See Figure 3.2 for an illustration of the set-up.
Figure 3.2: The vibration acuity measurement set-up used in this study. The signal travels from the signal generator (a), to both the computer (b.i) where it is read, as well as the amplifier (b.ii), which sends the signal to the vibrator (c). The black arrow in (c) corresponds to where individuals rested his or her finger. The black lines represent wires connecting the devices.
Two tests were performed using the vibration system: a test of amplitude sensitivity (Greening and Lynn, 1998; Hubbard et al. 2004) and a novel test of frequency sensitivity. For the amplitude test participants were asked to place the tip of their second digit gently on the vibrator, with his or her forearm supported to the wrist and were told to maintain that position for the duration of the test. A modified version of Greening and Lynn’s (1998) protocol was used for this test. The test frequency was held at a constant frequency of 120 Hz. In order to prevent sensory accommodation to the stimulus, the stimulus was turned on followed by a 3 second rest period at which point the vibration was turned off and the signal amplitude was decreased (Hubbard et al. 2004). The on-time for this study differed from Greening and Lynn (1998), however, in that it was the amount of time it took to turn the stimulus on, pause, and turn the stimulus off. In total the stimulus was on for approximately 3 seconds. Once the stimulus could no longer be perceived, it was increased again to just above the participant’s threshold and decreased more gradually until it could no longer be detected. This was done to determine the exact amplitude where detection was lost. The same procedure was carried out in the opposite direction; that is starting with the stimulus off and increasing it in order to determine where the individual was able to detect the vibration. Each direction was tested three times, alternating directions of testing, and a mean threshold determined over the three trials in each direction was taken. The overall vibration threshold was determined to be the average of the mean amplitude for sensory loss and the mean amplitude for sensory detection (Greening and Lynn, 1998).

For the second test, participants were asked to switch the finger on the vibrator so that the tip of digit three was gently resting on the probe. Again, the forearm was supported to the wrist. The amplitude of the signal generator was increased to a maximal level so that it was constant between subjects. From there the frequency was increased in approximately 25 Hz increments
from 200 Hz until the stimulus could no longer be detected. Again the stimulus was applied for approximately 3 seconds followed by a 3 second rest period in order to prevent accommodation. The outcome measure for this test was the maximum frequency that could be detected by each participant. Again, this test was performed three times and the overall threshold was taken as an average of the three trials.

Unfortunately, despite numerous efforts to calibrate the vibration system, the actual amplitude of the vibration of the probe was too small to measure. This amplitude, however, was less than 1 mm, and likely within a range of 0.1 – 400 µm, as consistent with Greening and Lynn’s (1998) system. We also attempted to determine the voltage coming out of the amplifier for various amplitudes of signals sent from the signal generator, however this measurement was so small that even our most sensitive equipment did not have the resolution to detect it. Therefore, the only measurable commodity for this test was the voltage and frequency of the signal sent to the computer and amplifier from the signal generator. Although this does not directly describe the actual vibration of the probe, it was apparent that the vibration amplitude changed in the same magnitude and direction when the parameters were changed on the signal generator.

The sensitivity of vibration sense has been shown to be quite variable using both vibrometers and tuning forks. For vibrometers the sensitivity ranges from 4%, in individuals with confirmed CTS who have vibration thresholds 1.65 standard deviations above a healthy individual of the same age, height and weight as listed in Gerr et al. 1990 (Werner et al. 1994), to 100%, in provoked CTS hands when compared with the same hands at rest (Borg and Lindblom, 1986), with an average of 45%. For tuning forks, the sensitivity ranges from 26%, in individuals with a median SNAP conduction velocity less than 50 m/s (Buch-Jaeger and Foucher, 1994), to 72%, in individuals with clinically diagnosed CTS who showed a difference in vibration sense
between the distribution of the median and ulnar nerves (Dellon, 1980), with an average of 58.4% (Massy-Westropp et al. 2000). Despite this difference in sensitivity between tuning forks and vibrometers, a vibrometer was used in this study. This is due to the fact that our at-risk group was expected to have very subtle changes in sensory acuity, which may not have been detectable using tuning forks. Pressure acuity is more sensitive and has been recommended as a diagnostic tool with an average sensitivity of 83%, with abnormal findings being defined as a pressure sense of approximately 0.07 g of pressure (Szabo et al. 1984; Buch-Jaeger and Foucher, 1994), for pressure acuity over four studies. For two-point discrimination, however, sensitivity was found to be low and deemed to be not useful in CTS diagnosis, with an average sensitivity of 20% over five studies (Massy-Westropp et al. 2000), with individuals with electrodiagnostically confirmed with CTS having two point discrimination ability greater than distances from 5 – 6 mm (Gerr and Letz, 1998; Buch-Jaeger and Foucher, 1994) and by MacDermid and Wessel in a 2004 review (MacDermid and Wessel, 2004). It was questionable whether or not two-point discrimination would be a useful test. For this study, these sensory impairment tests were used to test individuals who were at risk of developing CTS, and not individuals who had CTS.

3.6.2 Fine Motor Skills Tasks

Two tests of motor function were performed in order to determine whether fine motor skills were affected in the individuals at risk for CTS, prior to developing clinical signs (Gupta and Mahalanabis, 2000). These tests included the Purdue Pegboard Test and a manual tracking task, as described by Bouwer et al. (2001). The Purdue Pegboard Test is designed to evaluate fine motor skills of the hand and the reliability of this test across time has been well documented (ICC_{3,k} ranging from < .60 to .79, when the test is administered once; ICC_{3,k} > .80 when three trials were performed) (Irvine et al. 2004; Buddenberg and Davis, 2000). Its usefulness as a
diagnostic tool for CTS, however, has not been established. For the purpose of this study, two tasks were performed using the Pegboard; one testing very dexterous movements and one testing movements that were not so fine. The less dexterous motor task consisted of putting as many pegs into the holes on the board as possible in the allotted time of 30 seconds. Only one hand was tested at a time and participants were allowed to place only one peg at a time. This task was performed three times with each hand, and adequate practice was given prior to the start of the test. The more dexterous test involved assembling a structure consisting of a peg, a washer, a collar and another washer and repeating this task as many times as possible in one minute. This test was modified from its original version in order to separate a participant’s affected hand from non-affected hand. In the original test, pieces are placed using alternating hands, however in this study, only one hand was used at a time so that an individual’s non-affected hand would not mask the condition seen in the other hand. Again, this test was performed three times with each hand and practice was given prior to the administration of the test.

The manual tracking task that was used in this study is the task first reported by Brouwer et al. (2001), and the protocol was that performed by subjects in Brouwer and Faris (2007), in which participants were asked to track a target cursor moving quasi-randomly around a square area on a computer monitor corresponding with a 13 cm x 13 cm area defined on a digitizing tablet, using a hand-held stylus. Participants’ wrists were fastened to the tablet using Velcro straps in order to ensure that the movement only came from the wrist and not the elbow or shoulder. Like the original study, the x, y coordinates of the stylus position and the cursor position were recorded at 50 ms intervals for a period of 60 seconds and each individual was tested at a fast speed (2.9 cm/sec) and at a slow speed (1.8 cm/sec). Each trial was repeated three times with each hand and the order of the tests was randomized. The error score for each trial was
determined as the root mean square (RMS) of the sum of the linear differences between the target and stylus position at each point. The RMS values were averaged over the three trials for each condition. These errors were recorded for both the entire task, as well as only those points in the innermost, bottom quadrant (full flexion tracking - bottom left for left handed individuals and bottom right for right handed individuals) which required individuals to move into wrist flexion in order to reach. This should have elicited the most deficits and thus been the hardest location to track successfully. Tracking variation was also used as an outcome measure. The set-up for this test is shown below in Figure 3.3. For further details about the way in which the cursor moved, please see the original publication (Brouwer et al. 2001). This task was used by Brouwer and Faris to study individuals with cumulative trauma disorders (not limited to carpal tunnel syndrome) and was found to have a sensitivity of 0.81 (Brouwer and Faris, 2007).
Figure 3.3: The set-up for the manual tracking task is displayed. The square outlined on the tablet corresponds to the white square seen on the computer monitor.
3.7 **Data Analysis**

All data were analyzed using Minitab V.14 (Minitab Inc., State College, Pennsylvania). For demographic data means and standard deviations were determined for each study group and analyses of variance (ANOVAs) were used to test for differences among the groups. For all outcome measures, the data were first tested for normality. For normally distributed data one-way ANOVA models were used to compare group values. For non-normally distributed data, Kruskal-Wallis non-parametric tests were used to compare the groups. Where significant group effects were found, Tukey’s (parametric) or non-parametric post hoc analyses were conducted \((\alpha=0.05)\) to determine which groups were significantly different from the others. Because this study was preliminary in nature, the \(\alpha\)-level was not adjusted to accommodate multiple comparisons. The statistical results did not differ when parametric and non-parametric tests were used, therefore all data in the results section are presented using means and standard deviations instead of medians and ranges.

Pearson’s correlations values were also calculated for each outcome measure to determine if there was any notable association with age. All subjects were pooled for these tests.
Chapter 4

RESULTS

4.1 PARTICIPANTS

4.1.1 CTS GROUP

Eleven participants were recruited into the CTS group, including nine females and two males. One of the males was excluded due to the results of his nerve conduction studies, which suggested a lack of any median nerve damage, and three females were excluded due to the presence of suspected cervical radiculopathy based on the clinical screening exam. Data from seven participants were used in the data analysis. Their average age was 36 years (range 26 – 51 years). The average weight of this group was 77 kg (SD 9 kg) and the average height was 165 cm (SD 7 cm). All were experiencing symptoms in their dominant hand consistent with mild CTS according to self reported symptoms and their questionnaire scores (mean scores ± SD for: main module of the DASH – 17.68 ± 10.5, work module – 17.39 ± 11.7, SSS – 2.44 ± 0.74, FSS – 1.63 ± 0.65) and six out of the seven participants tested had a positive Phalen’s test and three of the seven had a positive Tinel’s sign. One individual tested negative on both Tinel’s and Phalen’s tests. They all also had electrodiagnostically confirmed median nerve sensory degradation, with a mean SNAP conduction difference of 0.79 ms (SD 0.45 ms) and a mean CNAP conduction difference of 0.5 ms (SD 0.44 ms), relative to the ulnar nerve. None of them showed signs of cervical radiculopathy or of nerve compression anywhere other than at the wrist. No deficits were seen in motor nerve conduction and motor function was not impaired. The demographic data are summarized in Tables 4.1, questionnaire scores are displayed in Table 4.2 and the occupations of each member of this group can be found in Appendix E.
**4.1.2 At-Risk Group**

Fourteen participants were recruited into the at-risk group, all of whom were female. The average age of this group was 45 years (range 27 – 54 years). The average weight was 66 kg (SD 11 kg) and average height was 166 cm (SD 7 cm). All participants in this group performed repetitive tasks at work with their dominant hand for at least five hours per day, however all were asymptomatic and scored very low on the questionnaires (mean scores ± SD for: main module of the DASH – 2.84 ± 4.38, work module of the DASH – 2.68 ± 5.86, SSS – 1.38 ± 0.55, FSS – 1.13 ± 0.17). All participants in this group had a negative Phalen’s test, and all except one had a negative Tinel’s sign. The demographic data are summarized in Tables 4.1 and 4.2 and the occupations of each member of this group can be found in Appendix E.

**4.1.3 Control Group**

Ten individuals were recruited to the control group (minimal risk group), however one was excluded due to an abnormally large conduction delay in the median nerve relative to the ulnar nerve. Nine control subjects were therefore used in the data analysis. The average age of the control group was 36 years (range 27 – 54 years). Their average weight was 66 kg (SD 13 kg) and their height was 168 cm (SD 9 cm). These subjects performed less than two hours of repetitive work with their dominant hand per day and all were asymptomatic as demonstrated by their questionnaire scores (mean scores for: main module of the DASH – 1.11 ± 1.02, work module of the DASH – 0 ± 0, SSS – 1.01 ± 0.03, FSS – 1 ± 0). All had a negative Phalen’s test and Tinel’s sign and none had abnormal median nerve conduction latencies relative to the ulnar nerve. The demographic data are summarized in Tables 4.1 and 4.2 and the occupations of each member of this group can be found in Appendix E.
Table 4.2: Demographic data for the three study groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Sex</th>
<th>Mean age (range)</th>
<th>Weight kg (SD)</th>
<th>Height cm (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTS</td>
<td>7</td>
<td>1 M, 6 F</td>
<td>36.14 (26-51)</td>
<td>76.70 (9.44)</td>
<td>165.36 (6.67)</td>
</tr>
<tr>
<td>At-risk</td>
<td>14</td>
<td>14 F</td>
<td>44.86 (27-54)</td>
<td>65.62 (11.16)</td>
<td>166.47 (6.73)</td>
</tr>
<tr>
<td>Minimal Risk</td>
<td>9</td>
<td>9 F</td>
<td>36.33 (27-54)</td>
<td>66.28 (12.88)</td>
<td>167.83 (8.68)</td>
</tr>
</tbody>
</table>

Table 4.2: Questionnaire scores for the three study groups for the DASH and the symptom severity scale (SSS) and the functional status scale (FSS) of the of the Boston Carpal Tunnel Questionnaire.

<table>
<thead>
<tr>
<th>Group</th>
<th>DASH main (SD)</th>
<th>DASH work (SD)</th>
<th>SSS (SD)</th>
<th>FSS (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTS</td>
<td>17.68 * (10.5)</td>
<td>17.39* (11.7)</td>
<td>2.44** (0.74)</td>
<td>1.63** (0.65)</td>
</tr>
<tr>
<td>At-risk</td>
<td>3.84 (4.38)</td>
<td>2.68 (5.86)</td>
<td>1.38** (0.55)</td>
<td>1.13* * (0.17)</td>
</tr>
<tr>
<td>Minimal Risk</td>
<td>1.11 (1.02)</td>
<td>0.00 (0.00)</td>
<td>1.01** (0.03)</td>
<td>1.00** (0.00)</td>
</tr>
</tbody>
</table>

*indicates a significant difference between the group and the other two groups (p < 0.05)

** indicates significant differences among all three indicated groups (p < 0.05)
### 4.2 Nerve Conduction Studies

Median nerve conduction times relative to the ulnar nerve conduction times were used to determine whether or not there were measurable differences between the individuals who performed repetitive tasks on a consistent basis and the control group. As these tests were also used to classify individuals who had CTS and those who were at minimal risk, it was only used to see where the data from the at-risk group fell in comparison to the two other groups. The mean values for the median to ulnar nerve SNAP conduction differences were 0.79 ms (SD 0.45 ms) for the CTS group, 0.20 ms (SD 0.20 ms) for the at-risk group, and 0.09 ms (SD 0.20 ms) for the minimal risk group. A group mean effect was seen in median nerve SNAP latencies (p = 0.001), however post hoc analysis revealed that significant differences were only present between the CTS group and the at-risk group (p = 0.002), and the CTS group and the minimal risk group (p = 0.001). There was not a significant difference between the at-risk group and the minimal risk group (p = 0.297). The findings were consistent with those from the median-ulnar CNAP latency differences (p = 0.01). The median-ulnar CNAP differences were 0.50 ms (SD 0.44 ms) for the CTS group, 0.14 ms (SD 0.16 ms) for the at-risk group and 0.14 ms (SD 0.16 ms) for the minimal risk group. Again, upon pairwise comparisons, it was clear that this difference reflected only a significant difference between the CTS group and both the at-risk and minimal risk groups, while the latter two groups were not different from each other (p values of 0.011, 0.025, and 0.996, respectively). Graphs comparing each nerve conduction test are presented in Figure 4.1.
Figure 4.1: Median-ulnar conduction latency differences, in ms, for a) SNAPs and b) CNAPs. Error bars represent 95% confidence intervals. *denotes a significant difference among groups.
4.3 Sensory Impairment Tests

For the sensory impairment tests, two-point discrimination and pressure sense data were unavailable from one of the CTS subjects due to technical difficulties. Thus the sensory impairment data included six CTS subjects instead of seven. Similarly data were unavailable from two of the CTS subjects for the vibration tests, therefore data analysis for these tests was completed with five CTS subjects instead of seven.

For two-point discrimination, the mean scores were 3.17 mm (SD 0.98 mm) for the CTS group, 2.64 for the at-risk group (SD 0.63 mm) and 3.0 (SD 0.87 mm) for the minimal risk group. There was no difference between the groups with regards to two-point discrimination (p = 0.377). For pressure sense, the mean scores were 0.30 g (SD 0.14 g) for the CTS group, 0.27 g (SD 0.17 g) for the at-risk group and 0.18 g (SD 0.17 g) for the minimal risk group. These differences were not significant (p = 0.255). For the high frequency vibration threshold the mean scores were 535 Hz (SD 276 Hz) for the CTS group, 581 Hz (SD 209.3 Hz) for the at-risk group and 561.1 Hz (SD 110.1 Hz) for the minimal risk group. Again, these differences were not significant (p = 0.684). For overall vibration threshold the mean scores were 553 mV (SD 315 mV) for the CTS group, 364.8 mV (SD 137.7 mV) for the at-risk group and 339.9 mV (SD 156.8 mV) for the minimal risk group; there were no significant differences found among the three groups (p = 0.107). Figures comparing the three groups are presented in Figures 4.2 through 4.4.
Two-point discrimination ability, in mm. Error bars represent 95% confidence intervals.
Figure 4.3: Pressure sense, in g of pressure. Error bars represent 95% confidence intervals.
Figure 4.4: a) High frequency threshold, in Hz, and b) overall vibration threshold, in mV. Error bars represent 95% confidence intervals.
4.4 **Fine Motor Skills Tasks**

Within the fine motor skills tests, only one significant difference was seen between the at-risk and the minimal risk group. This difference was seen in the assembly task of the Purdue Pegboard Test, with a mean score for the at-risk group of 27 pieces (SD 2 pieces) and a mean score for the minimal risk group of 30 pieces (SD 3 pieces). This difference was significant (p = 0.044). The CTS group scores were similar to those of the control group, with a mean score of 29 pieces (SD 2 pieces), and was not significantly different from either of the groups (p = 0.182 versus at-risk, p = 0.966 versus control). Only data from five CTS subjects were used for analysis. For the peg task of the Purdue Pegboard Test, the mean score for the CTS group was 15 pegs (SD 1 peg), the mean score for the at-risk group was 15 pegs (SD 1 peg) and the mean score for the control group was 16 pegs (SD 1 peg). This difference was not significant (p = 0.337). Once again, data from only five CTS subjects were used in the analysis on this test. For the manual tracking tasks (slow tracking error, variation and full flexion tracking, and fast tracking error, variation and full flexion tracking), data from only six CTS subjects were used in the analysis and none of these tasks proved to be significantly different among the groups (p values for the tasks respectively: 0.326, 0.427, 0.197, 0.264, 0.206, 0.452). Mean values for these tasks can be seen below in Tables 4.3 and 4.4.
Table 4.3: Mean scores and standard deviations for Purdue Pegboard Tasks

<table>
<thead>
<tr>
<th>Group</th>
<th>Purdue Pegboard Assembly Task</th>
<th>Purdue Pegboard Peg Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of pieces (SD)</td>
<td># of pegs (SD)</td>
</tr>
<tr>
<td>CTS</td>
<td>29 (2)</td>
<td>15 (1)</td>
</tr>
<tr>
<td>At-risk</td>
<td>27 (2)*</td>
<td>15 (1)</td>
</tr>
<tr>
<td>Minimal risk</td>
<td>30 (3)*</td>
<td>16 (1)</td>
</tr>
</tbody>
</table>

* indicates a significant difference between the two groups (p<0.05)

Table 4.4: Performance for slow (S.) and fast (F.) tracking tasks, as well as tracking in full flexion (flex.)

<table>
<thead>
<tr>
<th>Group</th>
<th>S. track error Mean (SD) in cm</th>
<th>S. track variation Mean (SD) in cm</th>
<th>S. track error – flex. Mean (SD) in cm</th>
<th>F. track error Mean (SD) in cm</th>
<th>F. track variation Mean (SD) in cm</th>
<th>F. track error – flex. Mean (SD) in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTS</td>
<td>0.24 (0.05)</td>
<td>0.14 (0.04)</td>
<td>0.22 (0.05)</td>
<td>0.39 (0.08)</td>
<td>0.25 (0.07)</td>
<td>0.40 (0.07)</td>
</tr>
<tr>
<td>At-risk</td>
<td>0.25 (0.03)</td>
<td>0.15 (0.03)</td>
<td>0.26 (0.08)</td>
<td>0.38 (0.04)</td>
<td>0.25 (0.03)</td>
<td>0.39 (0.04)</td>
</tr>
<tr>
<td>Min risk</td>
<td>0.23 (0.04)</td>
<td>0.13 (0.03)</td>
<td>0.21 (0.04)</td>
<td>0.35 (0.06)</td>
<td>0.23 (0.04)</td>
<td>0.36 (0.06)</td>
</tr>
</tbody>
</table>
4.5 **CORRELATIONS WITH AGE**

All measures were also tested to see if there were any significant correlations in task performance with age. All subjects were pooled for this analysis due to the fact that there were no group differences in age at testing among the three groups. For the most part, there were no correlations in performance with age. There were a few notable exceptions, however. It was found that performance in sensing light pressure as well as the fast manual tracking task showed significant deteriorations in older participants. The Pearson’s correlation values were 0.426 for pressure sense (p = 0.024) and 0.393 for the fast manual tracking error (p = 0.035). It is also noteworthy that the slow manual tracking error and the Purdue pegboard assembly task both showed trends towards a correlation with age. The Pearson’s correlation values for these tests were 0.336 (p = 0.075) and -0.347 (p = 0.071), respectively. All correlations were in the expected direction, with an increase in age correlating to decreased performance on the task.
Chapter 5

DISCUSSION AND CONCLUSIONS

5.1 SYNOPSIS

Despite the small sample size (5-7, 14, and 9 for the CTS group, at-risk group and control group respectively) and the generally negative result, there was some valuable information gained from this study. On the whole, sensory testing seems incapable of identifying individuals at risk for developing CTS. It appears, rather, that in conjunction with sensory nerve action potential conduction latencies, tasks involving high levels of manual dexterity may be promising early indicators of those individuals whom are on route to developing CTS. In order to confirm this, a larger sample must be tested.

5.2 PARTICIPANTS

5.2.1 RECRUITMENT

Due to the specific criteria set for each of the three study groups, subject recruitment proved to be one of the major challenges of completing this study. In the end, the number of subjects in each of the groups was relatively low, which is one of the main limitations of this study. For the recruitment of our CTS participants, a physiatrist at St Mary’s of the Lake Hospital was actively recruiting subjects, and posters and flyers were distributed to every physiotherapy clinic in the downtown Kingston region. Despite these efforts over a period of one year, only 10 CTS participants were recruited. Of these, two subjects had other complications, and were excluded from data analysis and one was screened out after the initial phone assessment, leaving seven subjects remaining. These low recruitment numbers are counterintuitive to the prevalence of CTS, which leads one to wonder what more could have been done to locate eligible
participants. Recruitment from physiotherapy clinics and doctor’s offices was low, so perhaps more frequent reminders to clinicians to refer participants (reminders were sent approximately every six weeks), or the provision of incentives for individual referral would have increased the success of this method of recruitment. Perhaps advertisements in newspapers would have also been more successful in recruiting participants.

For the recruitment of our at-risk participants, flyers and posters were left at every dental office in the downtown region with the purpose of recruiting the hygienists who work there, as well as at all ultrasound clinics, to recruit ultrasound technicians. These strategies were only slightly more successful than the recruitment of CTS subjects, likely because we were recruiting the individuals who worked at these locations, and it did not require these individuals to act as a middle party to recruit other individuals. Fourteen subjects were recruited for this group, with the majority of them being dental hygienists. One of the hygienists that participated in the study sent out a request to the society of dental hygienists in Kingston, which proved to be immensely more successful than just distributing flyers and posters at offices. This highlighted the importance of having a contact within a group of employees to spread the word about the need for participants. It was found that individuals were much more likely to participate if they were approached by someone that they were familiar with, as opposed to a stranger.

With the control group, word of mouth proved to be the best method for locating and recruiting participants. Individuals who knew teachers or nurses who could be persuaded to participate worked much better than posting flyers and posters in school staff rooms or nurse stations in hospitals. It is our thought that individuals in this group were reluctant to participate, as they did not have anything directly to gain from participation in this study. They were not at risk for the condition being studied so it seemed to not be of any interest to them. It was also
difficult to find individuals who performed less than two hours of repetitive work throughout the day, as many professions, as well as individual hobbies, revolve around the use of a computer. After much effort, nine control participants were recruited to participate. Two more individuals responded to posters but did not meet the inclusion criteria for any group and thus were excluded from the study.

This study incorporated testing of individuals from a variety of professions, and it is felt that there was good representation of different professions within the groups. The distribution of professions in the at-risk group provided a representative sample of individuals who were exposed to a variety risk factors for the development of CTS. There were a number of dental hygienists, who not only performed repetitive movements, but also performed these movements in sustained awkward postures. There were university administrators, customer service representatives, medical transcriptionists and secretaries who spent the greater part of the work day typing on the computer or doing mouse work. There was also a graduate student who spent many hours at the computer who has also been knitting for more than 20 years, for multiple hours a day. Our CTS group was selected with no bias towards the profession with which the participant works. These participants were administrators, dental hygienists, a concrete layer and a baker. For our control group we had the most success recruiting participants who were nurses (or nursing students), and teachers, who did not perform many repetitive tasks with their hands or wrists throughout the day. There was also a corrections officer in this group.

Within our groups, it is felt that a variety of tasks which are specific to the group to which they are assigned have been covered in this study. With increased recruitment, these samples would be an accurate representation of their respective populations.
5.2.2 Subject Matching

All participants in this study except for one were female. There was one male who participated in the CTS group. The CTS group was not sex matched to the other groups, due to the difficulty in finding participants, as well as to the fact that this group was not involved in our primary comparison. The purpose of the CTS group was to identify the expected magnitude and direction of any change in each outcome measure, in order to classify where the at-risk group should fall, provided there was a difference between the at-risk and control groups. Between our two main comparison groups, the at-risk and the control group, individuals were sex matched, which was necessary as males and females may respond differently to the tests performed (Tremblay et al. 2002).

Individuals who participated in this study were intended to be matched for age between the groups, although given the difficulties with recruitment this proved to not be possible. Despite the mean of the at-risk group being slightly older than the other two groups, there was no significant difference between the groups, and all groups covered similar age ranges. This was an important factor as there were significant correlations seen between performance and age. In particular in the pressure sense and fast manual tracking tasks, there were significant decreases in performance with increases in age. There was a similar trend seen in another two tasks – the slow manual tracking and the Purdue assembly task, although these correlations were not statistically significant. Performance on the original Purdue assembly task has been shown to decline with age (Derosiers et al. 1995; Haward and Griffin, 2002). All participants in this study were required to be younger than 60 years of age, due to the fact that drop offs in nerve conduction and thus sensory and motor function are seen after this age (Lexell et al. 1983; McComas et al. 1993). It can be expected, however, that this reduction doesn’t happen suddenly at 60 years old, and this
may be driving the correlations mentioned above. Based on the Pearson’s correlation values, it is possible that some of the older participants may have already been experiencing slight degradations in performance on some of the tasks in this study. If there was a significant difference in the ages between the groups, we would be unable to conclude that any differences in outcome measure were due to the repetitive tasks that they performed at work, and not due to a decrease in sensory and motor abilities associated with aging.

One factor that we didn’t control for, which may have played a role in the differences that were seen is body mass index (BMI). Obesity has been shown to be a risk factor for the development of CTS (Stallings et al. 1997), and our CTS group had a higher mean body weight than the other two groups, although this difference was not significantly different. If our control group, happened to have a higher BMI than our at-risk group, it could have placed them in an elevated risk situation, despite performing lower levels of repetitive work, and may have accounted for a lack of difference seen in some of the tasks. In our current sample, the groups were not significantly different in weight and our at-risk and control were almost identical, therefore this was not likely a factor. However, controlling for this factor would have made an already very difficult subject recruitment, even more difficult.

BMI was not calculated for this study, and instead, height and weight were displayed in the demographic table. This was due to the fact that nerve conduction velocity is dependant on nerve length, which is proportional to an individual’s height (Preston and Shapiro, 1998). By displaying height and weight, instead of BMI, it was seen that our groups did not differ in height and thus this was likely not a factor affecting the nerve conduction studies performed in this study.
5.2.3 Questionnaire Scores

The group scores on the two questionnaires showed that the groups were separated properly, and that in fact, both our at-risk and our control groups were asymptomatic. On both the main portion of the DASH and the work module of the DASH, the CTS group scored significantly higher than the at-risk group and the control group, which were, as expected, not significantly different from each other. This questionnaire is scored out of 100, with 0 being a complete absence of symptoms and 100 being extreme symptoms. Both the at-risk and control groups had mean scores below 4, which indicates a very low occurrence of symptoms associated with upper limb injury. With the Boston Carpal Tunnel Questionnaire, the score is recorded from 1 to 5, with 1 being a lack of symptoms (SSS) or no functional difficulties (FSS) and a 5 corresponding to severe symptoms, very frequently (SSS) or severe functional difficulties (FSS). Despite all three groups being significantly different from each other on both the SSS and FSS, the at-risk and the control groups both had mean scores less than 1.4, which corresponds to very low occurrence of mild symptoms and next to no functional difficulties. These data demonstrate that both the at-risk and the control groups were asymptomatic, while subjects in the CTS group were suffering with symptoms as well as mild functional disabilities.

5.3 Nerve Conduction Studies

For both the SNAP testing and CNAP testing, significant differences were seen between the CTS group and the control group and the CTS group and the at-risk group. This was expected as nerve conduction study results were used as a means of verifying group classification. For the SNAPs, the mean of the at-risk group fell between the control group and the CTS group, however this difference was not statistically significant, despite a 0.11 ms difference. This was likely due to the large variation in outcomes seen within each group and due to the small sample size. This
was confirmed through power calculations. This difference may end up becoming significant with further subject recruitment. With the current sample size and variation, power analysis for these data showed a power of 25%. In order to obtain 80% power, based on our effect size, 48 subjects would need to be tested per group. For the CNAPs, the at-risk group mean and standard deviation were identical to those of the control group. This discrepancy from what was seen in the SNAPs could have been due to a more variable electrode placement in the CNAP testing. With the SNAP recording, the recording electrodes remained in the same site for the recording of median SNAPs and ulnar SNAPs, and the stimulating probe was shifted between the two nerves. In contrast, with the CNAPs, both the probe and the recording electrodes were shifted between the two nerves. In hindsight, it may have been more precise if the distance between the recording electrodes and the probe was re-measured for the stimulation of the ulnar CNAP latency. This would have prevented any subtle differences in recording distance to occur which, when dealing with time frames as small as fractions of milliseconds, could potentially make a difference in the observed conduction latencies.

Bovenzi et al. (2000) tested individuals who were exposed to repetitive hand vibrations through the use of chainsaws, which is a risk factor for the development of repetitive strain injuries including CTS. This group found that individuals who were exposed to prolonged hand-transmitted vibration had slowed median and radial nerve conduction when compared to workers who were not exposed to vibration and healthy controls (Bovenzi et al. 2000). The fact that decreased conduction was seen in both the median and radial nerve suggests that there were problems at hand apart from or in conjunction with CTS, such as hand-arm vibration syndrome. In the current study, it was ensured that individuals who were specifically at risk for CTS were
recruited, and thus a difference in study populations as well as sample size may account for the differences in results seen between the two studies.

When it comes to nerve conduction studies, there are guidelines for normal values and abnormal values (see section 3.4). These values were used to help classify our CTS and control populations, but no restrictions were put on the at-risk population. Despite the lack of a significant difference seen between the at-risk and control groups, throughout the course of this study, it was observed that three of our at-risk individuals had SNAP latency differences which fell into the classification of abnormal. This goes to show that sensory nerve testing may be valuable in detecting individuals at risk, which will only be confirmed by following these individuals to determine if they start to develop signs of CTS. Conversely, there was an asymptomatic, healthy control subject who was excluded due to abnormally slowed nerve conduction which indicates that due to high levels of individual variation, a diagnosis cannot be made based on sensory nerve testing alone.

5.4 Sensory Impairment Tests

None of the sensory impairment tests that were used in this study showed any significant differences between the groups. For pressure sense, the at-risk mean was higher than the control group, and lower than the CTS group, however, compared to the variations within each group, the group differences were very small. For this test, as well as the test of two-point discrimination ability, it makes sense that no difference was seen among the three groups. The two-point discrimination test is not sensitive enough to determine the degree to which a sensory nerve is impaired – it can only determine whether or not it is transmitting at all (Kandel et al. 1991). None of our participants were experiencing numbness, only chronic irritation of the nerve which caused symptoms like pain and paraesthesias, thus, all had functional sensory neurons. If there were any
sensory losses in any of the groups, it is likely that they were minor and that this test of two-point discrimination was not sensitive enough to measure this impairment.

These results agree with results found by Robinson and Kincaid (2004), who found that there were no significant differences between string musicians and control subjects, when comparing two-point discrimination within hands (i.e. right compared to right; left compared to left) between groups. However they did find that there was a significantly higher percentage of phalanges in both hands with decreased two-point discrimination in musicians than in controls (Robinson and Kincaid, 2004). None of these comparisons, however, controlled for hand dominance, and the authors did not separate the groups based on sex. Comparisons were also not restricted to the distribution of the median nerve and it is possible that the percentage of phalanges with elevated two-point discrimination could be inflated by phalanges within the distribution of the ulnar nerve, which could also be damaged in string musicians (Lederman, 1989).

Gupta and Mahalanabis (2006) showed that there was a trend toward decreased two-point discrimination ability in the thumb of shoemakers who performed highly repetitive movements with their thumb to place a rubber strap into a pair of sandals, however this difference was not significant (Gupta and Mahalanabis, 2006). Because the thumb performed repetitive movement, and not the wrist, it is likely that any nerve damage occurred specifically to the digital nerves of the first phalanx which would hinder their sensory ability. It is likely that conduction to the rest of the distribution of the median nerve would have been unaffected if measurements had been taken elsewhere. This could explain the discrepancy seen between these results and the current study. Calluses caused by repetitive use of the thumb may also have been responsible for the differences seen.
A similar explanation to why no difference was seen among the groups for two-point discrimination can be applied to the pressure sense results as well. Again, the likelihood of our participants experiencing significant sensory loss is low and this test of pressure sense would unlikely be sensitive enough to detect this impairment. It is likely that in the event that some sensory receptors were lost, due to the large amount of overlap among receptive fields, there would still be many more functional receptors which could detect the stimulus, and thus all groups would have comparable pressure senses (Kandel et al. 1991). This would explain why all of our study participants, regardless of group, scored within the same five filaments out of a possible 10, and why the outcome was not dependant on group assignment. The group means found for this test were 0.30 g, 0.27 g and 0.18 g, for the CTS, at-risk and control groups respectively, however the filaments used spanned a range from 0.16 g to 0.4 g. All three group means therefore fell between the pressure ratings of the same two filaments and it is therefore obvious that these discrete filaments limit the sensitivity of the test. That said, since the pressure values of the at-risk group fell between those of the control group and the CTS group, pressure sense may be a useful tool in detecting individuals at risk of developing CTS, however any pressure test used would have to use a continuous measure of pressure acuity.

The individual variation seen on pressure acuity measurements may also have been attributed to the variation in the skin thickness at participants’ finger tips or the presence of calluses. These data were not recorded in this study.

Again, these results agree with those found by Robinson and Kincaid (2004) who showed no significant differences in group means for light touch threshold between string musician and control participants when hands were matched for side. Like two-point discrimination, it was found that a significantly higher percentage of phalanges showed decreased pressure sense in the
musicians than in the control group, however comparisons were not controlled for sex or handedness (Robinson and Kincaid, 2004). Again, comparisons were also not restricted to phalanges within the distribution of the median nerve.

In our study, it took approximately 6 minutes to complete the two-point discrimination test and approximately 8 minutes to complete the pressure sense test on one testing location. To repeat these tests 10 more times for all of the phalanges within the distribution of the median nerve, in order to determine the percentage with increased sensory threshold, would have required a very large amount of time and would be unfeasible as a screening tool to test all workers who perform repetitive work.

In theory, vibration sense has the potential to be a valuable screening tool because it is a very subtle sensory function, just like grating orientation seen in a study by Tremblay et al. (2002). After attempting to purchase vibration testing equipment, it was found that such equipment was unavailable commercially, and thus we resorted to constructing our own equipment. With the equipment that we were using to test vibration sense, it was very difficult to be consistent, which may have led to some problems with our testing procedure. For the outcome measure to be recorded for this test, the investigator was required to turn the amplitude dial on the signal generator until the participant responded that they no longer felt the vibration, at which point the investigator stopped turning the dial and recorded the vibration level. This procedure is inherently variable as it required the reaction time of both the participant and the investigator, however this was the best method that was available for testing this variable, and likely reflected what would be done in clinical practice. The device that we settled on was the third attempt at finding a way to test vibration sense, and it proved to be the most reliable, however it still had its flaws. One of the major flaws was that we were unable to calibrate the system to determine what
each electrical signal amplitude corresponded to in terms of the amplitude of the vibration of the probe, as mentioned in section 3.6.1. It was assumed that the difference in voltage would be adequate in testing vibration sense, as a difference in vibration amplitude was clearly felt, however we do not know for certain that the relationship between voltage output and vibration amplitude was linear. From the start of the study, this was a known limitation, however we were hoping that despite the inability to quantify the amplitude of the vibration, we would be able to determine whether or not vibration sense was a feasible means of identifying at risk individuals. That is, despite not being able to provide absolute measurements (in mm) for vibration sense, we would be able to comment on whether it was an appropriate method. Unfortunately, due to the inherent error in our system we could not make this conclusion as it is impossible to determine whether or not there actually was a lack of difference between the three study groups, or we were just unable to detect differences that were in fact, there.

This difficulty that we had in designing a system that could reliably measure vibration thresholds should serve as a warning to others planning to use such a test for screening or patient assessment. Without readily available commercial tools for measuring vibration sense, it would be impractical, if not impossible for industry to use this as a screening method for individuals at risk of developing CTS.

It was observed that the overall vibration threshold was higher for the CTS group than the at-risk and the control group, who were fairly similar, but this difference was not statistically significant and wide variation was seen within each of the groups. This could indicate that there is decreased vibration sense in individuals with CTS, which is not present in at-risk individuals, however we cannot draw any conclusions based on the limitations discussed above. Greening and Lynn’s study (1997) was the basis for the majority of the vibration testing protocol used in the
current study, and these authors found that there were elevated vibration thresholds in the
distribution of the median nerve in individuals who were at risk of developing a repetitive strain
injury. Greening and Lynn’s system used a 120 Hz vibration signal (which was the same as the
current study) that ranged in amplitude between 0.1 – 400 µm, and used a similar protocol to the
current study. That is, they used alternating on and off periods of signal application and
calculated thresholds in the same way, using vibration perception and vibration loss.

Due to the difficulty seen in testing vibration sense in individuals, it may have been more
effective to use another test, such as the grating orientation test used by Tremblay et al. (2002) to
test subtle sensory function. This may have been easier to ensure reliability and consistency, and
may also be more effective in an industrial setting. Tremblay et al. (2002) used this test and found
decreased ability to detect which way gratings were oriented in frequent computer users, versus
occasional computer users.

5.5 **Fine Motor Skills Tests**

Based on the current results, it seems plausible that certain fine motor skills test may have
some potential for use as a screening tool for determining individuals at risk of developing CTS.
Theoretically, this makes sense in that tests that involve more dexterity would highlight
functional impairments more effectively than tasks that require minimal sensorimotor integration.
Dexterity is difficult if there are sensory impairments in the hands as an individual’s ability to
manipulate small items is hindered (Kandel et al. 1991).

The only significant difference seen between the at-risk group and the control group in
this study was in the assembly task of the Purdue Pegboard Test, which was the most dexterous
test used in the study. While the at-risk group performed significantly worse than the control
group, the CTS group proved to not be different from either of the two groups. This may be accounted for by the fact that data from only five of the seven CTS subjects were available for the analysis of this test. Five subjects are not a good representation of this group, and it is possible that those who participated were exceptionally good at this task. No significant difference was seen in the peg task of the Purdue Pegboard Test, which may be explained by the fact that this task is not nearly as dexterous as manipulating the nuts and washers of the assembly task.

To the author’s knowledge, no authors have previously used the Purdue Pegboard Test as a way of comparing individuals at risk of developing CTS with those not at risk, or even to classify individuals that already have CTS. No authors have reported having modified the test to be a one-handed test. This was a novel approach to analyzing this population, but was necessary to ensure that deficits noted were clearly generated by the hand deemed to be at-risk. Dexterity tasks have been used in past studies. Tremblay et al. (2002) showed a significant decrease in dexterity in the left hand (non-dominant) of female frequent computer users versus female occasional computer users, using a grooved pegboard task. A similar trend was seen in the right hand however the difference did not reach significance. Males tended to show comparable performance in both groups (Tremblay et al. 2002). Tremblay et al.’s results are comparable to the manual dexterity test used in the current study, in that females who performed frequent repetitive tasks at the wrist were significantly less dexterous that those who did not.

In all of the manual tracking tasks used in this study, the at-risk group had a higher mean tracking error and higher tracking variation than the control group, although again, each test showed large variance and none of the differences were found to be significant. Power calculations for this test showed a power of 35% and in order to obtain 80% for the observed effect size, 34 subjects per group would need to be tested. This task involved repetitive flexion
and extension of the wrist (more so in the fast tracking than in the slow tracking task) which theoretically would elicit symptoms in individuals with CTS and those at risk for the condition if any were present. It can be postulated that this difference would theoretically be more pronounced in the lower inner quadrant due to the fact that this location required the individual to move their wrist into full flexion. This difference was seen between controls and individuals with cumulative trauma disorders in the original reference by Brouwer et al. (2001). No such difference was found in this study. This discrepancy may be due to the fact that individuals in the original study were more strongly afflicted with symptoms of repetitive strain injuries than those that participated in the current study. Performance was seen to decrease in this task as a function of impairment level (Brouwer and Faris, 2007), and as impairment was minimal or non existent for our study groups (even the mild CTS group only scored an average of approximately 17 out of 100 on the main portion of the DASH) it is possible that our groups were not at a stage where diminished tracking ability might be seen. It seemed that this task did not involve enough fine dexterity to elicit any very subtle changes in the at-risk group, or even in the mild CTS group. It was also noted that many participants did not go into full wrist flexion in order to reach the lower inner quadrant. This could be a product of the instructions given by the researcher for the individual to begin by placing their hand comfortably so that it was possible to reach all points of the tracking surface. This could potentially explain why this test, in this case, did not elicit symptoms or demonstrate group differences. In further studies, hand position should be more standardized so that the individual is required to go into full wrist flexion in order to track the cursor. This may elicit more deficits in the CTS and at-risk groups (if deficits are in fact, present) which may show group differences.
One noteworthy observation throughout the course of this study is that some of the control participants seemed to be uncomfortable or awkward performing tasks that involved fine motor skills. The individuals who were in this group were not habituated to performing dexterous tasks with their hands. The at-risk group, on the other hand, was used to performing such dexterous tasks, and despite any potential decreases in ability caused by early changes associated with median nerve impingement, a difference between the at-risk and control group may have been cancelled out by this difference in experience and therefore ability. This possible explanation, in conjunction with the small number of participants in the CTS group, could potentially account for the lack of statistically significant differences seen in these manual tracking and peg tasks.

5.6 Implications and Future directions

Through the results of this pilot study it appears that sensory nerve conduction and fine motor skills testing show the most promise in screening individuals at risk of developing CTS for early signs of the condition. Through this study it was found that these sensory testing appeared not to be sensitive enough nor reliable enough to any changes in sensory nerve conduction or it appeared that sensory changes simply do not exist. Once again, the subject numbers for this study were quite low, and hopefully with increased subject recruitment as subject numbers approach 20 for each of the three groups, we may be able to tease out some differences between the control and the at-risk groups, by increasing the power of the study. With a larger sample size, a multivariate regression analysis may be useful to determine if performance in any of the measures (or combinations thereof) can accurately predict the group assignment of study participants.

This study used a cross sectional design in order to test which outcome measures could potentially be used to identify individuals with early signs of CTS. This study design is not the
best way to test this, but it was the only method which was feasible in the allotted time period and could provide evidence that a longitudinal study might be feasible. This study used individuals who frequently performed tasks known to place individuals at risk for the development of CTS and compared them to individuals who were not deemed at risk in order to determine if there were any neurological, sensory or functional tests that could distinguish those at risk from those with minimal risk. It cannot be assumed that every individual in the at-risk group will imminently develop CTS. An ideal study design to determine if these individuals can be identified before the condition becomes problematic would be a longitudinal study following the at-risk population to determine if any of them go on to develop CTS. The results of this investigation can be used to help guide such a study. Specifically, screening tests to be used in a longitudinal study should include SNAPs and fine motor skills testing, and should not include these sensory impairment tests. If it is in fact possible to determine which employees are at imminent risk of developing CTS, early intervention studies could then be developed and tested.

5.7 **Conclusions**

The purpose of the current pilot study was to determine whether or not there were any measurable sensorimotor changes that were evident in a group of individuals who performed repetitive tasks at work which subjected them to the development of CTS.

From the results seen in this study, individuals who perform repetitive occupational tasks which put them at risk for the development of CTS do not demonstrate any measurable sensory impairment and no significant differences were seen between any of the groups on the sensory impairment tests. Based on the results of this study the best predictors of the early development of CTS may be sensory nerve conduction studies, where there was a trend towards decreased median to ulnar sensory nerve conduction latency in the at-risk group compared to the control
group, and the Purdue assembly task performed with one hand, where the at-risk group performed significantly worse than the control group. A future longitudinal study following at-risk individuals to investigate the predictive values of these tests may demonstrate that early signs of developing CTS may be detectable, however, for now the results of this study only provide insight into this possibility.
REFERENCES


Appendix A

CONSENT FORM

TITLE OF PROJECT:

Sensorimotor testing for the early identification of individuals at risk of developing carpal tunnel syndrome

BACKGROUND INFORMATION:

You are being invited to participate in a research study directed by Dr. Linda McLean, Associate Professor in the School of Rehabilitation Therapy at Queen’s University. The study will investigate whether deficits in sensory or motor function exist in individuals at risk of developing, but not showing any symptoms, of carpal tunnel syndrome, which is caused by compression of the median nerve at the wrist. Carpal tunnel syndrome is a common nerve disorder, especially in individuals who are in occupations that involve high levels of repetitive work. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board and the information in this consent form will be reviewed with you and all procedures described in detail.

DETAILS OF THE STUDY:

1. **The aim of the study:**
   The purpose of this study is to determine whether or not measurable changes in sensory and motor nerve properties and functional abilities are seen in individuals who are at risk of developing carpal tunnel syndrome (CTS), but have not yet shown any clinical symptoms.
2. **Description of visits and tests to be performed as part of the study:**

Only one visit will be required for your participation in this study, and will take place in the Louise D. Acton Building at Queen’s University. You are eligible to participate if you are over the age of 18 and have mild or no carpal tunnel syndrome without any other neurological disorders. The time required during this visit will be approximately 1 hour.

On arriving at the laboratory, you will be asked to fill out two short questionnaires regarding symptoms associated with CTS and functional abilities. This will be followed by a short physical examination of your wrist and a nerve conduction study which will test the integrity of your nerves. This will involve placing two electrodes on your fourth finger. The areas will be rubbed vigorously with an alcohol swab to improve electrode adhesion and signal quality. Two nerves at your wrist (the median and ulnar nerves) will be stimulated using low levels of electrical current and the responses generated will be recorded on a computer. The results of the nerve condition tests will be used to make sure that you fit the study requirements. If there is evidence that you have more severe carpal tunnel syndrome based on this assessment, you will be withdrawn from the study.

Next you will be asked to perform three sensation tests. In the first test, a device with either one or two prongs will be touched to your finger tips and you will be asked to determine if you are being touched with one prong or two. The next test will involve fine wires touched to your finger tips. This time you will be asked to determine whether or not you can detect the pressure when the wires are pushed. Finally, you will place your finger on a vibrating device which vibrates at different frequencies and you will be asked to determine if you can feel the vibration or not. Your vision will be blocked during all of these tests.

The last two tests are used to test your fine motor skills. In the first test, you will be timed to see how long it takes you to manipulate a series of small objects, moving them from one location to another. In the second test, you will use a pen and a drawing tablet, and you will be asked to follow a cursor with your pen to see how accurately you are able to do this.
If you are in the at-risk group and fall within 20\textsuperscript{th} percentile of normal on three or more tests, you will be invited back after six months and again at one year in order to determine if there is any change in your test scores or if any symptoms have CTS have arisen, but you are not be required to participate at that time if you are not interested.

3. **Risks/Side-Effects:**

It is possible that symptoms of carpal tunnel syndrome, such as numbness, tingling or burning, may be aggravated by the physical examination of the wrist, although any symptoms you experience should not be different from what you normally experience and should not last longer than five minutes.

The nerve stimulation probe may cause some discomfort, however if the discomfort becomes unbearable then the level of stimulation will be decreased, or the stimulation will be stopped altogether and you will be free to withdraw from the study.

When using any electrical equipment there is a risk of electrical shock. The clinical EMG system is designed specifically to minimize this risk. As such, the risk of using the electrical equipment in this study is lower than using any of the electrical appliances that you use every day, such as a stereo or a television.

4. **Benefits:**

While you may not benefit directly from this study, results from this study may improve the understanding of carpal tunnel syndrome and may benefit those at risk CTS in the future. If early indicators are seen in individuals at risk of developing CTS, then preventative measures can be put into place to save individuals the pain, discomfort or lost work time that commonly results from this condition.

5. **Exclusions:**

You will not be able to participate in this study if any of the following are true:
• Have more severe carpal tunnel syndrome, meaning that there is evidence that your muscles are weak due to this condition
• Have had surgery to correct carpal tunnel syndrome in the past
• Have any metabolic condition or neuromuscular disease, such as cervical radiculopathy, stroke or diabetes that might affect the results of the study

6. Confidentiality:
All information obtained during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be identified in any records using a subject number only. Data will be stored in a filing cabinet and will be available only to the investigator (Robert Trachter) and the faculty advisor, Dr. Linda McLean. You will not be identified in any reports, publications or educational material that is developed based on this work.

7. Voluntary nature of study/Freedom to withdraw or participate:
Your participation in this study is voluntary. You may withdraw from this study at any time and your withdrawal will not have any consequences to you now or in the future. Your data will be removed from the analysis if you wish for it to be withdrawn.

8. Liability:
In the event that you are injured during your participation in this study, appropriate first aid and management advice will be provided and access to medical care, if necessary, will be arranged. By signing this consent you do not waive your legal rights nor release the investigators from their legal and professional responsibilities.

SUBJECT STATEMENT AND SIGNATURE SECTION:
I have read and understand the consent form for this study. I have had the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I
have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems or adverse events, I can contact

Dr. Linda McLean (Faculty Advisor) at 613-533-6101

OR

Dr. Elsie Culham (Departmental Director) at 613-533-6727

If I have questions regarding my rights as a research subject I can contact
Dr. Albert Clark, Chair, Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board at 613-533-6081

By signing this consent form, I am indicating that I agree to participate in this study.

_______________________  _________________
Signature of Patient   Date

_______________________  _________________
Signature of Witness   Date

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and demands, benefits, and risks involved to participants in this study.

_________________________  _________________
Signature of Principal Investigator   Date
Appendix B
RECRUITMENT POSTERS

Do you have Carpal Tunnel Syndrome?

We are investigating sensory and motor function in individuals with carpal tunnel syndrome and those at risk of developing carpal tunnel syndrome.

If you are aged 18-60 and have mild carpal tunnel syndrome then you may qualify for this study and we would like your help!

This study is led by Dr. Linda McLean and Robert Trachter of the School of Rehabilitation Therapy at Queen's University

If you would like more information about this study, please contact us.

Robert Trachter
Tel: 613-533-6000 x 77850 or 613-532-9223
e-mail: 3rt2@queensu.ca
Do you perform repetitive work on a daily basis? Are your colleagues developing Carpal Tunnel Syndrome?

We are investigating sensory and motor function in individuals who perform repetitive jobs with their hands on a daily basis.

If you are aged 18-60 and have been performing repetitive work for 5 years or more then you may qualify for this study and we would like your help!

This study is led by Dr. Linda McLean and Robert Trachter of the School of Rehabilitation Therapy at Queen's University

If you would like more information about this study, please contact us.

Robert Trachter
Tel: 613-533-6000 x 77850 or 613-532-9223
email: 3rt2@queensu.ca
HEALTHY VOLUNTEERS WANTED

We are investigating sensory and motor function in women who are not at risk of developing repetitive strain injuries and are in need of healthy participants.

COMPENSATION AND PARKING ARE PROVIDED AND THE TWO HOUR SESSION CAN BE SCHEDULED FOR EVENINGS OR WEEKENDS!

If you are:
• Between 18-60 years old,
• Have no neurological or musculoskeletal disorder affecting your upper limbs, and
• Do not perform repetitive tasks at work and spend little time on a computer

Then you may qualify for this study and we would like your help!

This study is led by Dr. Linda McLean and Robert Trachter of the School of Rehabilitation Therapy at Queen's University.

If you would like more information about this study, please contact us.

Robert Trachter
Tel: 613-533-6000 x 77850 or 613-532-9223
email: 3rt2@queensu.ca
Appendix C

SUBJECT INFORMATION FORM

SUBJECT NAME:  
DOB:  
SEX:  
HEIGHT:  
WEIGHT:  
HANDEDNESS:  
AFFECTED HAND:  

OCCUPATION:  
DURATION OF CURRENT EMPLOYMENT:  
PREVIOUS EMPLOYMENT:  
DURATION OF PREVIOUS EMPLOYMENT:  
DURATION OF SYMPTOMS (IF APPLICABLE):  
DO YOU PERFORM ANY REPETITIVE TASKS IN YOUR FREE TIME (KNITTING, SEWING, PLAYING A MUSICAL INSTRUMENT, COMPUTER USE, WOODWORKING, ETC)?  
IF SO, WHAT TYPE OF ACTIVITIES AND FOR HOW LONG?

SUBJECT NUMBER:  
CLASSIFICATION GROUP (PRE-SCREENING):  
CLASSIFICATION GROUP (POST-SCREENING):  
INCLUSION IN STUDY:  
YES  NO  

Physical Examination:  
Phalen’s test:  
Tinel’s sign:  
Cervical radiculopathy:  

1. Two-point discrimination

<table>
<thead>
<tr>
<th>Distance (mm)</th>
<th>Testing Order</th>
<th>Trial 1 Response</th>
<th>Trial 2 Response</th>
<th>Trial 3 Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (single prong)</td>
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<tr>
<td>2</td>
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<td>3</td>
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<tr>
<td>5</td>
<td></td>
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</tbody>
</table>
2. Neurological Examination:

Room Temperature:

**SNAPs:**

Skin temperature:
Median SNAP negative peak latency (wrist):
Median SNAP negative peak latency (antecubital fossa):
Ulnar SNAP negative peak latency (wrist):
Radial SNAP negative peak latency:

**CNAPs:**

Skin temperature:
Median CNAP negative peak latency:
Ulnar CNAP negative peak latency:

**CMAPs:**

Skin temperature:
Median CMAP onset latency (wrist):
Median CMAP amplitude (wrist):
Median CMAP onset latency (antecubital fossa):
Median CMAP amplitude (antecubital fossa):

3. Pressure acuity

<table>
<thead>
<tr>
<th>Filament applied</th>
<th>Testing Order</th>
<th>Trial 1 Response</th>
<th>Trial 2 Response</th>
<th>Trial 3 Response</th>
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<tr>
<td>1.65</td>
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<tr>
<td>3.22</td>
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</tbody>
</table>
### 4. DASH Score:

### 5. Manual Tracking

<table>
<thead>
<tr>
<th>Speed</th>
<th>Hand</th>
<th>Testing Order</th>
<th>Trial 1 Error</th>
<th>Trial 2 Error</th>
<th>Trial 2 Error</th>
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</thead>
<tbody>
<tr>
<td>1.8 cm/sec</td>
<td>Right</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Left</td>
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<tr>
<td>2.9 cm/sec</td>
<td>Right</td>
<td></td>
<td></td>
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<td></td>
<td>Left</td>
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</table>

### 6. Purdue Pegboard

<table>
<thead>
<tr>
<th>Test</th>
<th>Hand</th>
<th>Trial 1 Result</th>
<th>Trial 2 Result</th>
<th>Trial 2 Result</th>
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<tbody>
<tr>
<td>Peg</td>
<td>Right</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Left</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Assembly</td>
<td>Right</td>
<td></td>
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<td></td>
<td>Left</td>
<td></td>
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</table>

### 7. Boston Carpal Tunnel Questionnaire Score:

### 8. Vibration Sense

<table>
<thead>
<tr>
<th>Frequency Detected</th>
<th>Testing Order</th>
<th>Trial 1 Response</th>
<th>Trial 2 Response</th>
<th>Trial 3 Response</th>
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<td>frequency</td>
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<td>------------------------------</td>
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<tr>
<td>Amplitude of loss of sensation (120Hz)</td>
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<tr>
<td>Amplitude of detection of vibration (120Hz)</td>
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<td></td>
<td></td>
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<tr>
<td>Overall vibration threshold</td>
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</table>
Appendix D

QUESTIONNAIRES

BOSTON CARPAL TUNNEL QUESTIONNAIRE

SYMPTOM SEVERITY

SCALE

The following questions refer to your symptoms for a typical twenty-four-hour period during the past two weeks (circle one answer to each question).

How severe is the hand or wrist pain that you have at night?

1. I do not have hand or wrist pain at night
2. Mild pain
3. Moderate pain
4. Severe pain
5. Very severe pain

How often did hand or wrist pain wake you up during a typical night in the past two weeks?

1. Never
2. Once
3. Two or three times
4. Four or five times
5. More than five times

Do you typically have pain in your hand or wrist during the daytime?

1. I never have pain during the day
2. I have mild pain during the day
3. I have moderate pain during the day
4. I have severe pain during the day
5. I have very severe pain during the day

How often do you have hand or wrist pain during the daytime?

1. Never
2. Once or twice a day
3. Three to five times a day
4. More than five times a day
5. The pain is constant

How long, on average, does an episode of pain last during the daytime?

1. I never get pain during the day
2. Less than 10 minutes
3. 10 to 60 minutes
4. Greater than 60 minutes
5. The pain is constant throughout the day

Do you have numbness (loss of sensation) in your hand?
1. No
2. I have mild numbness
3. I have moderate numbness
4. I have severe numbness
5. I have very severe numbness

Do you have weakness in your hand or wrist?
1. No weakness
2. Mild weakness
3. Moderate weakness
4. Severe weakness
5. Very severe weakness

Do you have tingling sensations in your hand?
1. No tingling
2. Mild tingling
3. Moderate tingling
4. Severe tingling
5. Very severe tingling

How severe is numbness (loss of sensation) or tingling at night?
1. I have no numbness or tingling at night
2. Mild
3. Moderate
4. Severe
5. Very severe

How often did hand numbness or tingling wake you up during a typical night during the past two weeks?
1. Never
2. Once
3. Two or three times
4. Four or five times
5. More than five times
Do you have difficulty with the grasping and use of small objects such as keys or pens?

1. No difficulty
2. Mild difficulty
3. Moderate difficulty
4. Severe difficulty
5. Very severe difficulty

**FUNCTIONAL STATUS**

**SCALE**

On a typical day during the past two weeks have hand and wrist symptoms caused you to have any difficulty doing the activities listed below? Please circle one number that best describes your ability to do the activity.

<table>
<thead>
<tr>
<th>Activity</th>
<th>No difficulty</th>
<th>Mild Difficulty</th>
<th>Moderate Difficulty</th>
<th>Severe Difficulty</th>
<th>Cannot Do at All Due to Hand or Wrist Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Buttoning of clothes</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Holding a book while reading</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Gripping of a telephone handle</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Opening jars</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Household chores</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Carrying grocery bags</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Bathing and dressing</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer every question, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your best estimate on which response would be the most accurate.

It doesn’t matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.
# Disabilities of the Arm, Shoulder and Hand

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

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

<table>
<thead>
<tr>
<th>NOT AT ALL</th>
<th>SLIGHTLY</th>
<th>MODERATELY</th>
<th>QUITE A BIT</th>
<th>EXTREMELY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NOT LIMITED AT ALL</th>
<th>SLIGHTLY LIMITED</th>
<th>MODERATELY LIMITED</th>
<th>VERY LIMITED</th>
<th>UNABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>NONE</th>
<th>MILD</th>
<th>MODERATE</th>
<th>SEVERE</th>
<th>EXTREME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

24. Arm, shoulder or hand pain.

25. Arm, shoulder or hand pain when you performed any specific activity.

26. Tingling (pins and needles) in your arm, shoulder or hand.

27. Weakness in your arm, shoulder or hand.

28. Stiffness in your arm, shoulder or hand.

29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (circle number)

<table>
<thead>
<tr>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULTY</th>
<th>SO MUCH DIFFICULTY THAT I CAN'T SLEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. (circle number)

<table>
<thead>
<tr>
<th>STRONGLY DISAGREE</th>
<th>DISAGREE</th>
<th>NEITHER AGREE NOR DISAGREE</th>
<th>AGREE</th>
<th>STRONGLY AGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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

A DASH score may not be calculated if there are greater than 3 missing items.
## Disabilities of the Arm, Shoulder and Hand

### Work Module (Optional)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is: ________________________________

1. I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty</th>
<th>Mild Difficulty</th>
<th>Moderate Difficulty</th>
<th>Severe Difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. using your usual technique for your work?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. doing your usual work because of arm, shoulder or hand pain?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. doing your work as well as you would like?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. spending your usual amount of time doing your work?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

### Sports/Performing Arts Module (Optional)

The following questions relate to the impact of your arm, shoulder or hand problem on playing your musical instrument or sport or both.

If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you: ________________________________

1. I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty</th>
<th>Mild Difficulty</th>
<th>Moderate Difficulty</th>
<th>Severe Difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. using your usual technique for playing your instrument or sport?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. playing your musical instrument or sport because of arm, shoulder or hand pain?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. playing your musical instrument or sport as well as you would like?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. spending your usual amount of time practising or playing your instrument or sport?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Scoring the Optional Modules:** Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.

An optional module score may not be calculated if there are any missing items.
### Appendix E

**INDIVIDUAL OCCUPATIONS BY GROUP**

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>OCCUPATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CTS</strong></td>
<td></td>
</tr>
<tr>
<td>CTS1</td>
<td>Unknown</td>
</tr>
<tr>
<td>CTS2</td>
<td>Unknown</td>
</tr>
<tr>
<td>CTS3</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>CTS4</td>
<td>University Administrator</td>
</tr>
<tr>
<td>CTS5</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>CTS6</td>
<td>Delivery Driver/Concrete Layer</td>
</tr>
<tr>
<td>CTS7</td>
<td>Baker</td>
</tr>
<tr>
<td><strong>At-Risk</strong></td>
<td></td>
</tr>
<tr>
<td>AR1</td>
<td>Physiotherapist/Graduate Student/Knitter</td>
</tr>
<tr>
<td>AR2</td>
<td>Customer Service Agent</td>
</tr>
<tr>
<td>AR3</td>
<td>Customer Service Agent</td>
</tr>
<tr>
<td>AR4</td>
<td>Customer Service Agent</td>
</tr>
<tr>
<td>AR5</td>
<td>University Administrator</td>
</tr>
<tr>
<td>AR6</td>
<td>Medical Transcriptionist</td>
</tr>
<tr>
<td>AR7</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>AR8</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>AR9</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>AR10</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>AR11</td>
<td>Dental Hygienist</td>
</tr>
<tr>
<td>AR12</td>
<td>Administrative Secretary</td>
</tr>
<tr>
<td>AR13</td>
<td>Administrative Secretary</td>
</tr>
<tr>
<td>AR14</td>
<td>Physician/Researcher/Violist</td>
</tr>
</tbody>
</table>
**Control**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CONT1</td>
<td>Correctional Officer</td>
</tr>
<tr>
<td>CONT2</td>
<td>Graduate Student</td>
</tr>
<tr>
<td>CONT3</td>
<td>Registered Physiotherapist</td>
</tr>
<tr>
<td>CONT4</td>
<td>Nursing Student</td>
</tr>
<tr>
<td>CONT5</td>
<td>Teacher</td>
</tr>
<tr>
<td>CONT6</td>
<td>Registered Nurse</td>
</tr>
<tr>
<td>CONT7</td>
<td>Climbing Instructor</td>
</tr>
<tr>
<td>CONT8</td>
<td>Occupational Therapist</td>
</tr>
<tr>
<td>CONT9</td>
<td>Nursing Student</td>
</tr>
</tbody>
</table>