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Department of Biomedical Engineering
University of Wisconsin
Madison, WI 53706

Psychomotor and Sensory Tests for Carpal Tunnel Syndrome

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Robert G. Radwin, PhD, Principal Investigator

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Table of Contents

List of Abbreviations

CTS	Carpal Tunnel Syndrome
F	F-statistic
F_{lower}	Lower Force Level
g	grams
U_{pper}	Upper Force Level
MVC	Maximum Voluntary Contraction
N	Newtons
NCS	Nerve Conduction Studies
OSHA	Occupational Safety and Health Administration
P	probability
PE	Physical Exam
SD	Standard Deviation
SX	Symptoms

List of Figures

List of Tables

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Abstract

The Wisconsin Test is a quantitative computer-controlled test battery designed for measuring sensory and psychomotor function. Industrial subjects were recruited from high-risk jobs for carpal tunnel syndrome to determine if subtle sensory and motor deficits were observable in a working population. These tests were studied for potential use as an injury surveillance instrument. A total of 208 subjects participated (73 males and 135 females). Participants completed a symptom survey, were given a physical examination, administered nerve conduction tests, and were tested using the Wisconsin Test battery.

New methods were investigated for evaluating sensory and motor function following carpal tunnel release. Candidates for carpal tunnel syndrome (CTS) surgical procedures underwent a physical examination and nerve conduction studies, and completed a symptom survey (N=36). The patients were administered the Wisconsin Test psychomotor and sensory test battery immediately before surgery, and again six weeks following surgery. The outcome variables included the dynamic sensory gap detection threshold and rapid pinch and release pinch rate.

Significant Findings

The greatest functional deficits were observed when nerve conduction findings were positive and were accompanied by either positive symptom survey outcomes or positive physical exam findings. The presence of symptoms alone were not significantly associated with motor deficits and no significant sensory threshold differences were observed among subjects categorized using any single criterion (i.e. nerve conduction, symptom reports, or examination).

Post-operative improvement was observed in the index finger gap detection threshold (42%) and average pinch rate (20%) for the surgical hands six weeks after surgery. The non-surgical hands did not exhibit similar improvements. The average pre-operative gap threshold for the surgical hand was 0.14mm (SD=0.11), which decreased six weeks post-operatively to 0.08mm (SD=0.06). The pre-operative non-surgical index finger was 0.10mm (SD=0.07) and slightly decreased post-operatively to 0.08mm (SD=0.06). The average 10% MVC pinch rate for the surgical hand was 6.65 pinches/s (SD=1.63) pre-operatively, which increased six weeks post-operatively to 7.96 pinches/s (SD=1.95). The nonsurgical hand was 6.89 pinches/s (SD=1.76) pre-operatively, which increased six weeks post-operatively to 7.37 pinches/s (SD=1.85).

Usefulness of Findings

The Wisconsin Test battery quantified functional deficits associated with CTS in an industrial setting. Psychomotor and sensory deficits were related to positive NCS findings accompanied by positive physical exams and symptoms. Symptoms alone were not significantly associated with these deficits. These findings were for a random industrial population in jobs considered high risk for CTS. The Wisconsin Test battery was able to distinguish differences in sensory and motor function between cases and controls in this study. These results hold promise that the Wisconsin Test battery may be a useful tool in workplace surveillance for CTS.

Measurable and quantifiable sensory and psychomotor deficits were observed in a working industrial population, and were greatest when positive symptoms or physical exam was accompanied by positive nerve conduction test findings. These data show that clinical criteria used in the diagnosis of carpal tunnel syndrome corresponds with functional psychomotor and sensory impairments measured in these tests.

Significantly greater improvement in patients was observed for the surgical hand than for the non-surgical hand six weeks following surgery in both sensory and psychomotor functional test outcomes.

1. Functional Deficits in Carpal Tunnel Syndrome

Introduction

Carpal tunnel syndrome (CTS) continues to be one of the most prevailing peripheral entrapment neuropathies, and is a major cause of reported occupational illness in the US (Phalen, 1972; BLS, 1999). Tanaka et al., (1994) estimates that one million US adults annually may have carpal tunnel syndrome requiring treatment. In the annual Survey of Occupational Injuries and Illness, 29,000 CTS cases resulting in days away from work were reported in 1997 (NIOSH, 2000). Practical tools that have a high sensitivity and specificity are therefore needed for active surveillance in programs to detect CTS. Such instruments might be used to identify developing CTS cases in high-risk jobs such as those requiring high force and high repetition (prevalence=5.6%), or in high-risk industries such as meatpacking (prevalence=21%) (Silverstein et al., 1987; Gorsche et al., 1999). It would be beneficial to periodically monitor workers in jobs like these for early detection of the disorder before it progresses, similar to the periodic use of hearing tests to investigate threshold shifts in workers who are occupationally exposed to noise.

This study investigates tests designed to monitor functional deficits associated with CTS in the context of using them for injury surveillance in the workplace. A computer-controlled test battery for detecting subtle sensory and psychomotor deficits associated with CTS was developed at the University of Wisconsin–Madison (Radwin et al., 1994; Jeng et al., 1994; Jeng and Radwin, 1995). These tests quantify sensory and motor function specific to the median nerve under highly controlled conditions. Both sensory and motor loss from CTS may result in functional deficits (e.g. difficulty in performing tasks at home or at work). The performance measures in these tests were suggested by functional activities in occupational tasks, such as repeatedly pressing a key or tactually inspecting a surface for a defect. A reduction in ability to rapidly pinch may be associated with a reduction in coordination and manual dexterity while handling objects or operating tools. A decrease in tactility or sensory loss may be associated with an inability to distinguish surface defects in tactile inspections tasks.

The psychomotor test measures coordination for a rapid pinch and release task utilizing specific muscles of the hand predominately innervated by the median nerve, including the index finger and thumb (Jeng et. al., 1997a; Jeng et. al., 1994). The sensory test involves actively probing a computer-controlled gap in a highly polished surface (Jeng and Radwin, 1995; Radwin et. al., 1994) using a method of limits threshold task. The palmar aspect of the index finger is tested because it is solely innervated by the median nerve.

Previous studies demonstrated that the Wisconsin Test Battery could differentiate well-defined CTS cases from confirmed normal subjects (Jeng et al., 1997a; Jeng et al., 1997b). When administered periodically to workers performing jobs associated with increased risk for CTS, suitable tests may detect subtle impairments in sensory and motor function early, before a disability occurs. The non-invasive test battery can be administered in as little as fifteen minutes at the workplace.

The purpose of the current study is to compare the Wisconsin Test battery measures of functional deficits associated with CTS in industrial subjects recruited from a variety of high-risk industrial settings, against criteria used for clinical diagnosis of CTS. Physical examination, symptom surveys and nerve conduction testing were therefore used as the gold standard for this study. It is hypothesized that hands with positive CTS criteria (i.e. positive physical exam, symptoms, and nerve conduction tests) require a significantly larger gap for detection and demonstrate a significantly slower psychomotor pinch rate than hands with negative CTS criteria.

Materials and Methods

The study was conducted in the Midwestern United States at five different industrial study sites. The types of companies and demographics of subjects participating are shown in Table 1. To date, 208 subjects (416 hands) have been tested, including 73 males and 135 females. The average age was 38.4 years (SD=9.2) and the age range was 18 to 60 years. The ethnicity was predominantly white, not of Hispanic origin (n=181). These demographic distributions were consistent for all of the participating plants. The maximum number of participants tested in each company was limited to 60 in order to distribute subjects among various industries.

Insert Table 1

Subjects were recruited from departments and divisions that were identified by their employer as high risk for CTS. This was confirmed by identifying CTS cases in OSHA logs and other company records, and by the presence of risk factors for CTS (i.e. repetitive motion, extreme wrist postures, forceful exertions, etc.) for specific jobs. Job analyses from videotapes were completed for all respective departments involved in the study to confirm the presence of risk factors. All subjects were volunteers and participated with informed consent. Participants were paid their regular hourly salary and the majority of volunteers were tested during working hours. The study protocol was reviewed and approved by the University of Wisconsin human subjects institutional review board.

Symptom Survey

All subjects completed a symptom survey, which contained questions about symptoms in the upper extremities, the type of work performed, and past medical history (i.e. diabetes, arthritis, thyroid disease, ruptured cervical disk, and renal failure). Information was also gathered relating to specific symptoms in the hand such as numbness, tingling or pain, and frequency, duration and magnitude of the symptoms. Each subject completed a self-reported hand diagram.

Physical Examination

All subjects also underwent a physical examination of the upper limbs, shoulder and neck, which included general range of motion and strength assessment and provocative tests (i.e. Phalen's and Tinel's tests) for the median nerve. A positive response to Tinel's and Phalen's sign required pain or paresthesia in at least one digit innervated by the median nerve.

Nerve Conduction Studies

Nerve conduction studies (NCS) were completed for both hands of each subject. All studies involved supramaximal stimulation. Median and ulnar transcarpal studies used supramaximal orthodromic stimulation over the distal palmar creases, and a 3cm recording bar electrode was placed proximal to the distal wrist crease at a distance of 8 cm (10 cm was occasionally necessary for larger hands and adjusted by an average conduction velocity of 50 m/s). Radial sensory studies utilized antidromic stimulation, at a distance of 10 cm proximal to a 3 cm recording bar electrode placed over the radial nerve as it was palpated over the extensor pollicus longus tendon.

The peak latency and baseline-to-peak amplitudes were recorded for each sensory nerve. Motor nerve conduction velocities were calculated between each stimulated segment. No needle examination was performed. All studies were conducted by experienced physicians using a TECA Sapphire (TECA – Oxford Instruments, Pleasantville, NY). Hand temperature was recorded over the dorsal first web space on one hand, and both hands were warmed if this temperature fell below 32 degrees Celsius.

Wisconsin Test Battery

All subjects were administered the Wisconsin Test battery. The automated aesthesiometer measures tactile sensitivity when the index finger freely probes a tiny gap on an otherwise smooth surface (Radwin et al., 1994; Jeng and Radwin, 1995). Gap detection sensory thresholds estimate the minimum width needed for detecting a gap in a smooth surface. What distinguishes this test from conventional tactility tests such as Semmes-Weinstein monofilaments or two-point discrimination, is that it measures tactile sensitivity using active touch rather than a passive tactile stimulus.

Subjects were allowed five seconds to probe the metal plate prior to determining the presence or absence of a gap. Gap size was changed using a micropositioner and digital encoder, which was controlled by a microcomputer. As the gap size was changed, subjects responded verbally if they could detect a gap using the converging staircase method of limits paradigm. Contact force was controlled at 50 g. An auditory signal masked the noise of the motor so that subjects were not aware if movement of the plates had occurred. Subjects were allowed to feel the gap closed and open at a fixed interval prior to testing. Both hands of all subjects were tested. Normative values are available in Jeng and Radwin (1995).

The rapid pinch and release test measures psychomotor performance in terms of speed and force control (Jeng et al., 1994). An aluminum strain gauge dynamometer is pinched using the index finger and thumb (Radwin, et al., 1991). A pinch strength test is first administered for determining maximum voluntary contraction (MVC) force. The subject is instructed to exert an MVC for five seconds and average force from the second to fourth seconds is measured. The objective of the rapid pinch and release test is to repetitively pinch the dynamometer with a force greater than an upper level (F_{upper}) and then release the force less than a lower level (F_{lower}) as quickly as possible. Force levels for F_{upper} include 10% and 20 % MVC and a fixed F_{lower} force level of 4% MVC. Visual and auditory feedback is provided to the subject upon obtaining the upper and lower force levels. Performance measures are pinch rate (i.e. pinches/s), overshoot force (% force above F_{upper})and the difference in pinch rate with respect to the two levels of F_{upper} (i.e. pinches/s/%MVC). A full description of this test and normative levels are in Jeng, et al. (1994).

The gap detection sensory test was administered first, followed by the rapid pinch and release psychomotor test. Rapid pinch and release practice sets were completed prior to data collection. One half of the subjects were tested with F_{upper}=20% first, followed by F_{upper}=10% and vice versa. Alternate hands were tested to allow for recovery between trials.

The data was analyzed for observable differences between symptoms, negative NCS findings, and physical exam findings according to specified criteria. To have positive symptoms, they had to occur at least weekly, the intensity had to be at least moderate, and pain or paresthesias had to be reported in the median distribution into the fingers. The criterion for a positive NCS was a transcarpal difference greater than 0.6ms. Either Tinel's, Phalen's or tenderness over the flexor wrist compartment was required for positive physical exam findings. Similar criteria are frequently used in clinical diagnosis of carpal tunnel syndrome.

Statistical Analyses

Analysis of variance was used for evaluating statistical significance of the gap detection thresholds, pinch rates, and change in pinch rate when stratified by symptoms, nerve conduction test outcomes and physical exam findings. Each hand was treated as an individual in all statistical analyses unless specifically indicated. Age was used as a covariate and was statistically significant ($p<.05$) for some of the functional test variables. Sixteen subjects (thirty-two hands) were excluded from the data analysis secondary to medical diagnostic confounders (e.g. rheumatoid arthritis, diabetes). Additionally, one of the excluded hands had physical exam findings and reported symptoms consistent with the diagnosis of cervical radiculopathy. Examiners were blinded to subject performance on other test parameters.

Results

Single Criterion for a Case

Subjects were designated as positive or negative based on physical exam, NCS, or symptoms. No statistically significant differences were observed for the gap detection thresholds or F_{upper} =20% MVC pinch rate among subjects categorized using just a single criterion of positive NCS, positive symptoms or positive physical exam findings. Subjects having +NCS findings had a F_{upper} =10% MVC pinch rate of 4.92 pinches/s while the subjects having –NCS findings had a F_{upper} =10% MVC pinch rate of 5.66 pinches/sec ($F(1,277)=3.80$, $p<.05$). No statistically significant differences were observed for F_{upper} =10% MVC overshoot among subjects categorized using a single criterion. Significant differences in pinch rate for F_{upper} =10% MVC were observed based on physical exam criteria ($F(1,283)=5.10$, $p<.05$) (Table 2). No statistically significant differences were observed for change in pinch rate with respect to F_{upper} (pinches/s/%MVC) using just NCS, symptoms or physical exam findings alone.

Insert Table 2

Combined Criteria for a Case

Subjects were classified based on combined outcomes of physical exam, symptom survey and NCS findings (Table 3). Those having either a positive physical exam or reported symptoms were classified +(PE/SX) and those with negative findings in both were classified –(PE/SX). Statistically significant differences between groups were observed for the F_{upper} =10% MVC pinch rate ($F(1,261)=2.86$,$p<.05$) and F_{upper} =10% MVC overshoot ($F(1, 261)=4.105$, $p<.05$). Tukey's post-hoc testing demonstrated significant differences between the +(PE/SX)/+NCS group and the other three groups for both F_{upper} =10% MVC pinch rate and F_{upper} =10% MVC overshoot.

Insert Table 3

Clinical Criteria for a Case

A strict clinical case definition of carpal tunnel syndrome was applied to designate cases and controls. A positive NCS finding, and either a positive physical exam or symptoms were required to be a positive case. If these conditions were not satisfied, the hand was designated a negative case. Subjects considered +CTS therefore had +PE or +SX, and +NCS. Otherwise, the subject was among the -CTS group.

Differences were observed for both sensory and psychomotor test outcomes when subjects were classified as +CTS or –CTS (Table 4). The average gap detection threshold for the +CTS group was 0.21mm while the –CTS group gap detection threshold was 0.15mm ($F(1,331)=5.52$, $p<.05$). The average gap detection threshold for the +CTS group required a 40% larger gap than the –CTS group.

Insert Table 4

The $F_{upper}=10\%$ MVC pinch rate for the +CTS group had an average of 4.20 pinches/s while the –CTS group had an average of 5.69 pinches/sec ($F(1,205)=4.09$, $p<.05$). Therefore the +CTS group demonstrated a 26% slower pinch rate than did the –CTS group. The $F_{upper}=10\%$ MVC pinch force overshoot for the +CTS group had an average overshoot of 41.37% as compared to the –CTS group which had an average of 23.86% overshoot. This represented a 73% greater pinch force overshoot for the +CTS group. Change in pinch rate also demonstrated significant differences ($F(1,175)=4.51$, $p<.05$). The –CTS group average change in pinch rate was –0.1578 pinches/sec%MVC while the +CTS group was -0.0056 pinches/sec/%MVC. This represented a 96% difference between the two groups.

Statistically significant demographic differences were observed between the +CTS and – CTS groups for age ($F(1,369)=17.98$, $p<.001$) and body mass index (BMI) ($F(1,355)=24.06$, $p<.001$). The +CTS group had a mean age of 43.12 years (SD=8.87) and a mean body mass index of 31.28 (SD=6.84). The –CTS group mean age was 36.98 years

(SD=8.74) and had a mean BMI of 27.04 (SD=4.96). Of the 41+CTS hands, 27 were female and 14 were male. Of the 330 –CTS hands, 214 were female and 116 were male.

Discriminant analysis performed using the Wisconsin Test battery variables demonstrated statistically significant ($p<.05$) differences between +CTS and –CTS groups. The canonical discriminant function coefficient was 0.15mm for the gap detection threshold (sensitivity = 0.49 and specificity = 0.69), 5.5 pinches/sec for F_{upper}=10% MVC pinch rate sensitivity = 0.72 and specificity = 0.63), 25.66 %MVC for F_{upper}=10% MVC pinch force overshoot sensitivity = 0.52 and specificity = 0.72), and 0.14 pinches/sec/%MVC for change in pinch rate sensitivity = 0.63 and specificity = 0.57). Combining the Wisconsin test variables resulted in a discriminant function with a sensitivity = 0.70 and specificity =0.78.

Discussion

Functional Deficits for CTS

A physical exam and nerve conduction study in combination with symptoms is the usual recommended gold standard for clinical diagnosis of CTS (Dawson et al., 1990; Kimura, 1989; Rempel, 1998). Studies where subjects are classified as +CTS or –CTS based on symptom reports alone may systematically misclassify disease status (Gerr, 1995). Although this combination of criteria is recommended, there is no universally agreed criterion for diagnosis of CTS (Homan et al., 1999). Therefore, the current study investigated differences in functional deficits associated with varying combinations of symptoms, physical examination and nerve conduction criteria.

When subjects were classified based on symptoms alone, psychomotor and sensory function between groups did not appreciably differ. Some statistically significant differences were observed when subjects were categorized based on NCS or physical exam findings for the variable pinch rate (F_{upper}=10% MVC). These results suggest that F_{upper}

=10% MVC pinch rate was related to electrophysiological parameters and physical exam findings regardless of symptoms.

Subjects were also classified based on combined PE, SX and NCS results. The +(PE/SX) group either had positive physical exam or symptom survey outcomes. The –(PE/SX) group had both negative physical exam and symptom survey findings. Jeng et al. (1997b) applied similar classifications and found significant differences between groups in all the Wisconsin Test variables; gap detection threshold, pinch rate and change in pinch rate. Subjects were recruited from volunteers in an industrial working population (Jeng et al., 1997b). The difference between the current study and Jeng et al., (1997b) is subject selection procedure and the number of subjects recruited. Individuals with CTS symptoms in Jeng et al., (1997b) were identified and classified as cases by an occupational health nurse, while individuals that reported no symptoms were classified as controls. In the current study, volunteers were selected based solely on their jobs. Subjects were subsequently examined and tested. No significant differences in any of the Wisconsin Test variables were observed for SX or PE except F_{upper}=10% MVC pinch rate. The +(PE/SX) and +NCS group performed an average 21% slower pinch rate than did the –PE/-SXS and –NCS study group. This seems to indicate that only the +(PE/SX)/+NCS group demonstrated pinch rate deficits.

The definition of +CTS in the current study is consistent with the clinical case definition for positive CTS often used for medical diagnosis and requires a positive NCS, and either a positive physical exam or positive symptoms. Using this definition we observed that there were significant sensory and psychomotor deficits in CTS for all the functional variables tested, with the exception of F_{upper}=20% MVC pinch rate. The +CTS subjects required a 40% average wider opening than the –CTS subjects in order to detect the gap. This was similar to the findings of Jeng et al., (1997a) where CTS cases had 104% greater average threshold than did the controls. They saw a larger difference between cases and controls quite possibly due to the range of differences in the cases and controls by selection. In those studies the extremes of the distribution of carpal tunnel syndrome were sampled (i.e.

spectrum bias). The controls were individuals specifically recruited due to absence of upper extremity symptoms, and cases were individuals with confirmed carpal tunnel syndrome. The current study recruited workers based on their job, which likely included subjects distributed over a range of conditions.

Although the pinch task predominately involves the median nerve, there is some ulnar nerve involvement due to it partially innervating the flexor pollicis brevis. This did not seem to obscure functional changes in CTS. Jeng et al., (1997b) similarly found that subjects who tested free of CTS demonstrated a faster pinch rate at F_{upper}=10% versus F_{upper}=20% whereas CTS cases did not demonstrate a change in pinch rate. The +CTS subjects in the current study also demonstrated a 26% average slower pinch rate (F_{upper} =10% MVC) than did the –CTS subjects. This finding was also supported by Jeng et al., (1997a) in which a 24% difference between cases and controls in pinch rate was observed.

Workplace Surveillance for CTS

A variety of surveillance approaches have been previously considered for identifying CTS in the workplace. These include symptom questionnaires, physical examination, and periodic monitoring tests (Waris et al., 1979; Fine et al., 1986).

Although questionnaires are perhaps the most sensitive indicator, examinations and tests improve specificity. Non-quantitative symptom provocative tests such as Phalen's and Tinel's signs are highly variable (Seror, 1988). Katz et al., 1991 reported sensitivity of 0.62 and 0.73 and specificity of 0.66 and 0.36 respectively for Phalen's and Tinel's signs. Use of these tests was shown to have poor sensitivity (50%) among patients with electrophysiologically confirmed CTS compared with subjects with or without hand pain, and no electrophysiological evidence of CTS (Gerr, 1994). These findings however were based on patients referred for nerve conduction tests as compared to subjects in this study, who continue to work and may have not necessarily sought medical attention. Additionally, routine physical examination for surveillance is costly and often prohibitive, particularly for large workplaces.

Vibrometry testing has been considered as a monitoring test for CTS, but these tests were shown to also lack sufficient sensitivity and specificity. Daily variations in vibrotactile thresholds reduce sensitivity and specificity of the test. Fagius and Wahren (1981) found intra-individual variation ranging from –59% to 58% compared to the first value measured. Gerr et al. (1995) found statistically significant group differences in vibrotactile thresholds between subjects with CTS and those without CTS, but this was only for thresholds obtained after ten minutes of provocative wrist flexion. Another problem with vibrotactile testing is the difficulty relating deficits in vibration detection thresholds to specific functional or physiological deficits.

Periodic electrodiagnostic tests have also been considered, but these medical tests are costly, time consuming and considered noxious by many, making them less than practical for routine monitoring for CTS. Electrodiagnostic testing such as nerve conduction studies (NCS) in conjunction with physical examinations are currently considered the most accurate diagnostic tests for CTS. The obvious advantage of testing the median nerve directly is the absence of subjective reporting. A study by Werner et al. (1997) found that electrodiagnostic methods for predicting future carpal tunnel syndrome in asymptomatic workers were not predictive of future hand and finger complaints. Franzblau and Werner (1999) considered nerve conduction velocity (NVC) tests to be an important tool in the clinical assessment of CTS but these test results must be interpreted cautiously. Portable nerve conduction devices have been studied and were not found to be useful in screening for early CTS cases (Pransky et al., 1997).

Positive CTS subjects in the current study and in earlier studies demonstrated both tactile deficits and psychomotor deficits, which support the utility of the Wisconsin Test battery for measuring functional deficits associated with CTS in a working population. Combining the Wisconsin test variables resulted in a discriminant function with a sensitivity = 0.70 and specificity =0.78. This concurs with the findings of previous studies in which a combination of test variables resulted in better sensitivity and specificity (Jeng et al., 1997a; Jeng et al., 1997b). Demographic differences between cases and controls were also observed. The +CTS group was older in age and had an increased BMI than the –CTS group. Previous studies have found similar relationships between increasing BMI and development of CTS. Werner et al (1997) found that age and obesity were risk factors for increasing prevalence of median mononeuropathies among a working population. In a study examining risk factors for carpal tunnel syndrome in a general population, Nordstrom et al. (1997) found, even after adjusting for age, that for each unit increase of BMI, the risk of CTS increased by 8%.

This study had several limitations that should be noted. Each hand was treated as an individual subject (i.e. +CTS and –CTS). Although this challenges the assumption of independence, since the two hands from the same subject may be correlated, treating each hand as a subject increases the degrees of freedom for statistical analysis. This approach was adopted for practical considerations since we did not want to exclude 50% of the hands tested. When the data was analyzed with the non-dominant hands excluded, significant differences between cases and controls were still observed for all variables, gap detection threshold ($F(1,146)=4.35$, $p<.05$, F_{upper}=10% pinch rate $F(1,116)=3.86$, $p=.05$ and change in pinch rate ($F(1, 95)=7.68$, $p<.01$). The magnitude of differences (26% to 96%) between +CTS and –CTS observed suggests that the results were robust despite the potential bias. The remaining individuals in the case group had one hand as a case and one hand as a control.

Another limitation of the current study comes from the symptom survey that was used. The survey was adapted from one used by NIOSH in numerous studies. In the original format, the survey was worded in such a manner that prevented investigators from assigning symptoms to individual hands. Therefore symptoms were assigned only to the hand identified by subjects as the "worse" hand. The survey did not identify symptoms by individual hands. It was therefore possible that some symptomatic hands for bilateral cases were misclassified as not experiencing symptoms (miss), potentially reducing the sensitivity of the survey. This survey was modified for subsequent testing so that subjects can assign symptoms to individual hands.

A notable strength of this study is that unlike in previous investigation where CTS patients seeking medical assistance were recruited in the electromyography (EMG) clinic, all subjects in the current study were recruited from a working population. In the current study, we attempted to minimize spectrum bias by categorizing cases and controls from the same industrial working population.

Deficits in sensory and motor function, as measured in the current study, revealed a quantifiable level of severity consistent with objective clinical findings. It is likely that most of the +CTS subjects in the current study involved CTS symptoms that were less severe or present at a sub-clinical level than the previous studies using EMG clinic subjects, many whom were preparing for surgery. This makes it more difficult to categorize subjects as +CTS or –CTS. Physical exam findings and symptoms may not be at a level that indicates that the subjects should be placed in the +CTS category, and therefore the subject was placed in the –CTS category even though they may have a +NCS outcome. Conversely, the subject may have recently developed symptoms that meet the criteria for the +(PE/SX) group, but due to being in the early stages of the disease process the median nerve may not be affected and therefore is classified in the –CTS group. Homan et al., (1999) found that the agreement between various combinations of screening procedures (e.g. symptom survey, physical exam and NCS) was poor and this may contribute to subjects being misclassified.

This study is being continued longitudinally and prospective data will be available in the future. In subsequent years those subjects may move into the +CTS group. These longitudinal studies will test if the utility of the Wisconsin Test battery for injury monitoring programs. The test battery may also be suitable for monitoring recovery from surgical, medical or ergonomic interventions. These questions are currently being tested in our laboratory.

CONCLUSIONS

The Wisconsin Test battery quantified functional deficits associated with CTS in an industrial setting. Psychomotor and sensory deficits were related to positive NCS findings accompanied by positive physical exams and symptoms. Symptoms alone were not significantly associated with these deficits. These findings were for a random industrial population in jobs considered high risk for CTS. The Wisconsin Test battery was able to distinguish differences in sensory and motor function between cases and controls in this study. These results hold promise that the Wisconsin Test battery may be a useful tool in workplace surveillance for CTS.

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Table 1 - Test Site and Subject Distribution

Company	Industry	Number of Subjects			Age*	BMI*†
		Male	Female	Total	(years)	
A	Plastics Manufacturer	10	13	23	35.83 (7.51)	26.56 (4.14)
B	Window Coverings Manufacturer	14	45	59	42.69 (7.98)	26.95 (4.75)
C	Turkey Processing Plant	10	36	46	38.46 (10.55)	30.05 (6.93)
D	Publishing and Printing	4	24	28	34.96 (10.21)	26.09 (4.57)
E	Automobile Assembly Plant	34	18	52	36.56 (7.65)	27.49 (5.17)
Total		72	136	208		

* Mean and (SD)
† Body-Mass Index (BMI)

Table 2 - 10% Pinch Rate for hands categorized by positive and negative symptoms* (Sx), nerve conduction study (*NCS*), *and physical exam (PE)

		Sx		NCS*		PE**	
		-	+	-	+	-	+
Number of hands		199	69	233	47	220	66
Pinch Rate (pinches/sec)	Mean	5.69	5.19	5.66	4.92	5.64	5.02
	SD	1.70	1.88	1.79	1.38	1.72	1.82

*p=.05
**p,<05

Table 3 - Functional Performance Variables for Physical Exam (PE) and Nerve Conduction Studies (NCS)

	PE/SX- NCS –		PE/SX+ NCS –		PE/SX- NCS+		PE/SX+ NCS+	
	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N
Gap detection threshold(mm)	.15 (.12)	16 9	.14 (.10)	92	.16 (.11)	22	.21 (.16)	35
20% Pinch Rate (pinches/sec)	4.96 (1.58)	15 7	4.64 (1.41)	84	4.87 (1.16)	22	4.35 (1.17)	35
10% Pinch Rate (pinches/sec)*	5.71 (1.74)	14 1	5.60 (1.90)	77	5.68 (1.10)	19	4.20 (1.34)	29
10% Overshoot (%MVC)*	25.32 (21.81)	14 1	22.48 (21.00)	77	21.85 (17.23)	19	41.38 (26.00)	29
Pinch Rate Difference (pinches/sec/%MVC)	-0.1386 (0.3008)	11 9	-0.1929 (.1954)	67	-0.1145 (0.2748)	18	-0.0056 (0.2419)	24

*p<.05 (Univariate snalysis of variance was used for evaluating statistical significance of the Wisconsin Test variables when combining variables of symptoms, nerve conduction test outcomes and physical exam findings.)

Table 4 - Functional Performance Variables for +CTS and –CTS groups

	-CTS		+CTS	
Variable	Mean (SD)	N	Mean (SD)	N
Gap detection	0.15	29	0.21	35
threshold(mm)*	(0.11)	9	(0.16)	
20% Pinch Rate	4.85	28	4.36	35
(pinches/sec)	(1.48)	3	(1.17)	
10% Pinch Rate	5.69	25	4.20	29
(pinches/sec)*	(1.73)	4	(1.34)	
10% Overshoot	23.86	25	41.38	29
(%MVC)*	(20.81)	4	(26.00)	
Pinch Rate Difference	-0.1578	22	-0.0056	24
(pinches/sec/%MVC)*	(0.2651)	0	(0.2419)	

*p<.05

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2. Functional Tests for Quantifying Recovery Following Carpal Tunnel Surgery

Objective. New methods were investigated for evaluating sensory and motor function following carpal tunnel release.

Design, Setting, and Patients. Candidates for carpal tunnel syndrome (CTS) surgical procedures underwent a physical examination and nerve conduction studies, and completed a symptom survey (N=36). The patients were administered the Wisconsin Test psychomotor and sensory test battery immediately before surgery, and again six weeks following surgery.

Main Outcome Measures. The outcome variables included the dynamic sensory gap detection threshold and rapid pinch and release pinch rate.

Results. Post-operative improvement was observed in the index finger gap detection threshold (42%) and average pinch rate (20%) for the surgical hands six weeks after surgery. The non-surgical hands did not exhibit similar improvements. The average pre-operative gap threshold for the surgical hand was 0.14mm (SD=0.11), which decreased six weeks post-operatively to 0.08mm (SD=0.06). The pre-operative nonsurgical index finger was 0.10mm (SD=0.07) and slightly decreased post-operatively to 0.08mm (SD=0.06). The average 10% MVC pinch rate for the surgical hand was 6.65 pinches/s (SD=1.63) pre-operatively, which increased six weeks post-operatively to 7.96 pinches/s (SD=1.95). The nonsurgical hand was 6.89 pinches/s (SD=1.76) pre-operatively, which increased six weeks post-operatively to 7.37 pinches/s (SD=1.85).

Conclusion. Significantly greater improvement in patients was observed for the surgical hand than for the non-surgical hand six weeks following surgery in both sensory and psychomotor functional test outcomes.

INTRODUCTION

Diagnosis of carpal tunnel syndrome (CTS) frequently results in surgery and prolonged work disability.[1] In 1999, carpal tunnel syndrome resulted in the highest median number of days away from work in the US, which was 27 days.[2] In addition to lost work time, workers with CTS often have difficulty returning to their previous job, and frequently must change occupations.[3] It is anticipated that quantitative evaluation of sensory and motor function following CTS surgical intervention could provide better assessment of rehabilitation for return to work.

Changes in physical examination and reported symptoms are normally observed following surgery, but rarely are nerve conduction studies repeated due to costs and the perceived noxious nature of the test. Katz et al.,[4] found that extended work absence correlated with worsening functional status of the hand, which was measured via a self-reported questionnaire.[5] An objective measure to quantify functional changes associated with CTS would therefore be important in the context of rehabilitation assessment in the clinic. When administered to patients before and after surgical intervention, such a test could quantify recovery and improvements in function and would permit quantitative evaluation of capacity to return to work. The effect of work modifications on CTS could also be monitored.

A computer-controlled test battery for measuring subtle sensory and psychomotor deficits associated with CTS was developed at the University of Wisconsin–Madison.[6 7 8] The performance measures in these tests were based on functional activities performed in occupational tasks, such as tactually inspecting a surface for a defect or repeatedly pressing a key. The sensory test involves detecting a computer-controlled gap on a highly polished surface.[6] The psychomotor task is a rapid pinch and release task utilizing specific muscles of the hand innervated by the median nerve, including the index finger and thumb.[7 9] Previous studies demonstrated that the Wisconsin Test battery could differentiate well-defined CTS cases from confirmed normal subjects[7 10] and CTS cases from controls in an industrial working population.[11]

The purpose of the current study is to evaluate the Wisconsin Test battery using patients who have undergone unilateral carpal tunnel release surgery, in the context of quantifying functional aspects of rehabilitation aimed at return to work. The contralateral hand was used as the control. Specifically it was hypothesized that the surgical hands would show greater improvement in sensory and psychomotor performance on the Wisconsin Test battery than the non-surgical hand.

METHODS

Participants were sequentially recruited from the offices of two hand surgeons in a Midwestern United States clinic. All subjects scheduled to undergo unilateral CTS surgery (surgical hand) had nerve conduction studies consistent with CTS. The contralateral hand not scheduled for surgery (non-surgical hand) was used as a control. Participants volunteered with informed consent and were paid a small fee for their service. The majority of subjects were tested immediately before or after their scheduled physician appointments.

Subjects were tested one to two days prior to surgery, and six weeks following surgery. A total of 36 subjects (72 hands) were tested, which included 10 males and 26 females. The mean age was 48.97 years (SD=13.54) ranging 26 to 85 years, with 14% (5) worker's compensation cases. Of these, a total of 30 subjects reported right hand dominance, while the remainder reported left hand dominance. The dominant hand was operated on 64% of the time. Endoscopic carpal tunnel release (2 portal Chow technique) was performed on 15 (42%) of the hands. The remaining 21 patients (58%) underwent open carpal tunnel release (small incision distal to the wrist crease).

All subjects completed a survey, which contained questions about symptoms in the upper extremities, occupation, and past medical history (e.g. diabetes, arthritis, thyroid disease, ruptured cervical disk, and renal failure). The information related to specific symptoms in the hand such as numbness, tingling or pain, and frequency, duration and magnitude of the symptoms. Each subject also completed a self-reported hand diagram. The Wisconsin Test battery consisted of functional sensory and psychomotor tests described below.

The automated aesthesiometer described by Radwin, et al.[6] measured tactile sensitivity while the finger freely probed a tiny gap on an otherwise smooth surface.[8 12] Gap detection sensory thresholds estimated the minimum gap width needed for detecting the gap. Both the index finger and small finger were tested on each hand. This allowed for comparison between areas innervated by the median and ulnar nerves. Subjects probed the gap for five seconds. Gap size was changed using a micropositioner and digital encoder, controlled by a microcomputer. As the gap size was changed, subjects responded verbally if they could detect a gap using the converging staircase method of limits paradigm.

Contact force was controlled at 50 g. A white noise auditory signal masked the noise of the motor so that subjects are not aware if movement of the plates had occurred.

The rapid pinch and release test measured psychomotor performance in terms of speed and force control.[7] An aluminum strain gauge dynamometer was pinched using the index finger and thumb.[13] The objective of the pinch and release psychomotor test was to pinch the dynamometer above an upper force level (F_{upper}) and then release below a lower force level (F_{lower}) as quickly as possible. Subjects performed the test using alternate hands and completed two conditions of F_{upper} (10 and 20 % MVC) for each hand and F_{lower} was fixed at 4 %MVC. Half the subjects were tested for F_{upper}=20% first and were tested for, F_{upper}=10% first.

The data was analyzed for differences between surgical and nonsurgical hands as well as differences pre and post operatively, and for differences between index and small finger gap detection thresholds, which are indicative of median and ulnar sensory function respectively. A full factorial analysis of variance with repeated measures was used for evaluating statistical significance of the functional performance variables, gap detection threshold and pinch rates when stratified by surgical versus non surgical hand and pre and post operative sessions. Age was not a statistically significant covariate.

RESULTS

The pre-operative and post-operative gap detection results are shown in Figure 1. Median sensory function improvement was observed in the average index finger gap detection threshold for the surgical hands six weeks following surgery. The average gap detection index finger threshold for the surgical hands improved by 42% ($p<.01$) while the nonsurgical hands only demonstrated a 20% improvement ($p=.10$). The interaction between surgical intervention and the pre-operative and post-operative hands was also statistically significant ($p<.01$).

In comparison to the index finger, the pre-operative and post-operative small finger gap detection thresholds are also reported in Figure 1. A 22% improvement ($p<.01$) was observed for the average small finger ulnar gap detection threshold for the surgical hands while the nonsurgical hands demonstrated no change ($p=.09$). The overall difference between pre-operative and post-operative testing for the small finger was statistically significant ($p<.05$) but a significant interaction with the surgical side was not observed ($p=.22$).

The preoperative and postoperative F_{upper} =20% MVC pinch rate and F_{upper} =10% MVC pinch rate results are reported in Figure 2. Statistically significant differences were observed prior and six weeks post surgery in the motor component for both F_{upper} =20% MVC pinch rate ($p<.001$) and F_{upper} =10% MVC pinch rate ($p<.001$). The average improvement was 18% for F_{upper} =20% MVC pinch rate and 20% for F_{upper} =10% MVC for the surgical side. The average improvement in F_{upper} =20% MVC pinch rate and F_{upper} =10% MVC for the nonsurgical hand was 7% for both. A significant interaction with surgical intervention and the pre-operative and post-operative hands was observed in F_{upper} =10% MVC pinch rate ($p<.05$) but not in F_{upper} =20% MVC pinch rate ($p=.067$).

No significant differences were observed in pinch MVC for either surgical or non-surgical hands pre and post surgery ($p=.20$). Prior to surgery, the surgical hand had an average pinch MVC of 42.13N (SD=14.64) while the non-surgical hand which had an average pinch MVC of 45.06N (SD=16.27). The surgical side average pinch MVC decreased by 8% while the non-surgical side increased by 2%.

Symptom intensity (1= no pain and 5=severe pain) and symptom frequency (1=never and 6=daily) also improved following surgery (Figure 3). An average 45% improvement ($p<.01$) in symptom intensity was reported for the surgical hands as compared to the nonsurgical hands which demonstrated a 19% improvement ($p<.01$). A statistically significant interaction for symptom intensity was observed between surgical side and pre-operative and post-operative hands ($p<.01$). Overall symptom frequency also improved, 37% ($p<.01$) for the surgical hands and 28% ($p<.05$) for the nonsurgical hands but the interaction between pre-operative and post-operative tests and surgical intervention was not significant ($p=.063$). No significant differences in symptom intensity or frequency were observed following surgery between surgical and nonsurgical hands.

DISCUSSION

Improvement in both sensory and psychomotor functional test outcomes was observed six weeks following carpal tunnel surgery. The magnitude of change for the functional performance on the Wisconsin Test variables for the surgical hands ranged from 18% to 43% while the average change for the nonsurgical hands was 7% for the psychomotor tests and 20% for the sensory tests. It is interesting to note that many of the subjects were either on restricted duty or off work following the surgery (average return to work was 3.5 weeks). The sustained rest and reduction in physical activities following surgery may have contributed to the improvement observed in nonsurgical hand median and ulnar nerve sensory function.

A physical examination and nerve conduction study in combination with symptoms is part of the standard diagnosis for CTS.[14 15 16] Rarely are nerve conduction studies repeated following surgery due to the perceived noxious nature of the test and associated costs. Therefore, it is usually not the practice to quantify electrophysiological improvement following carpal tunnel release surgery. The Wisconsin Test may provide an alternative non-invasive measure for quantifying recovery.

The results from this study indicate that the Wisconsin Test battery may be useful in monitoring functional improvement following surgical, medical and ergonomic interventions. This information is useful since worsening upper extremity functional status has been reported as a predictor of work absence.[17] The observed changes were measured in a relatively short time interval, six weeks following surgery. Future studies should measure functional changes for a longer period, such as six months following surgery, where additional functional improvement may be observed.

Sesto, Radwin and Salvi[18] conducted physical examinations and nerve conduction studies on selected employees recruited from various workplaces that were identified by their employer as high risk for CTS, and observed functional performance in the Wisconsin Test during working hours. Subjects free of CTS findings had an index finger average gap detection threshold of 0.15 mm (SD=0.11, N=299 hands), and 10% MVC pinch rates of 5.69 pinches/s (SD=1.73, N=254 hands). Subjects with findings consistent with CTS had significantly greater sensory thresholds and slower pinch rates. Although little distinction was observed between the average performance of subjects in the current study and CTS free subjects in the previous study, statistically significant improvements on average were observed following surgical intervention. Many of the subjects in the current study did not have work-related CTS (86%) or they were away from work for some time due to their scheduled CTS surgery, which may explain their better performance than the industrial workers presenting positive CTS findings, but still working.

Although no significant differences between surgical and non-surgical hands were observed prior to surgery or again following surgery, this effect may be due to many of the subjects reporting bilateral CTS symptoms. Within one year, 50% (18) patients underwent subsequent surgery on the contralateral (non-surgical hand). The data supports the common clinical finding of bilateral disease.

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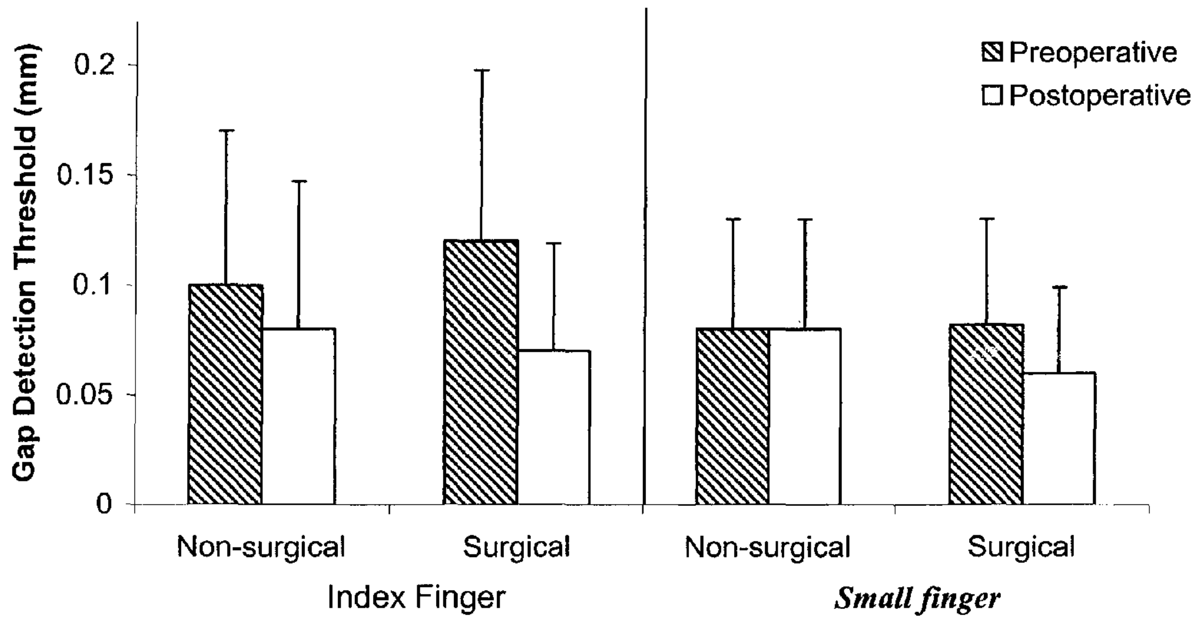

Figure 1 – Average (+1 SD error bars) preoperative and postoperative index and small finger gap detection threshold for surgical and non-surgical hands

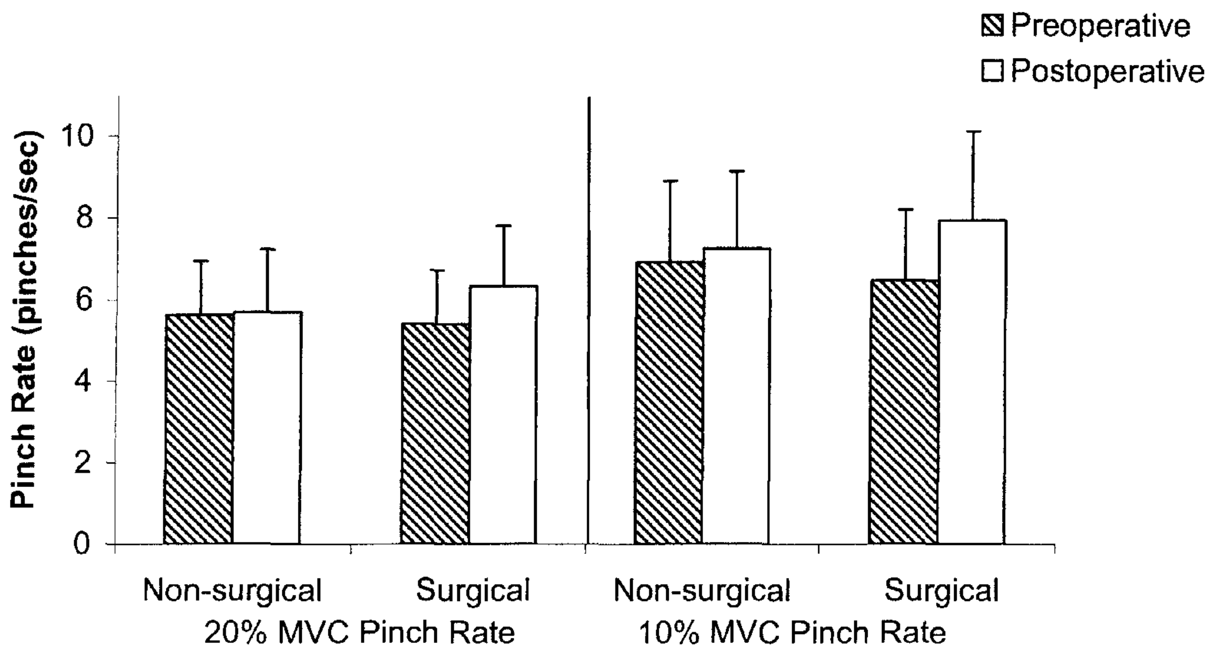

Figure 2 – Average (+1 SD error bars) preoperative and postoperative 20% and 10% pinch rate for surgical and non-surgical hands

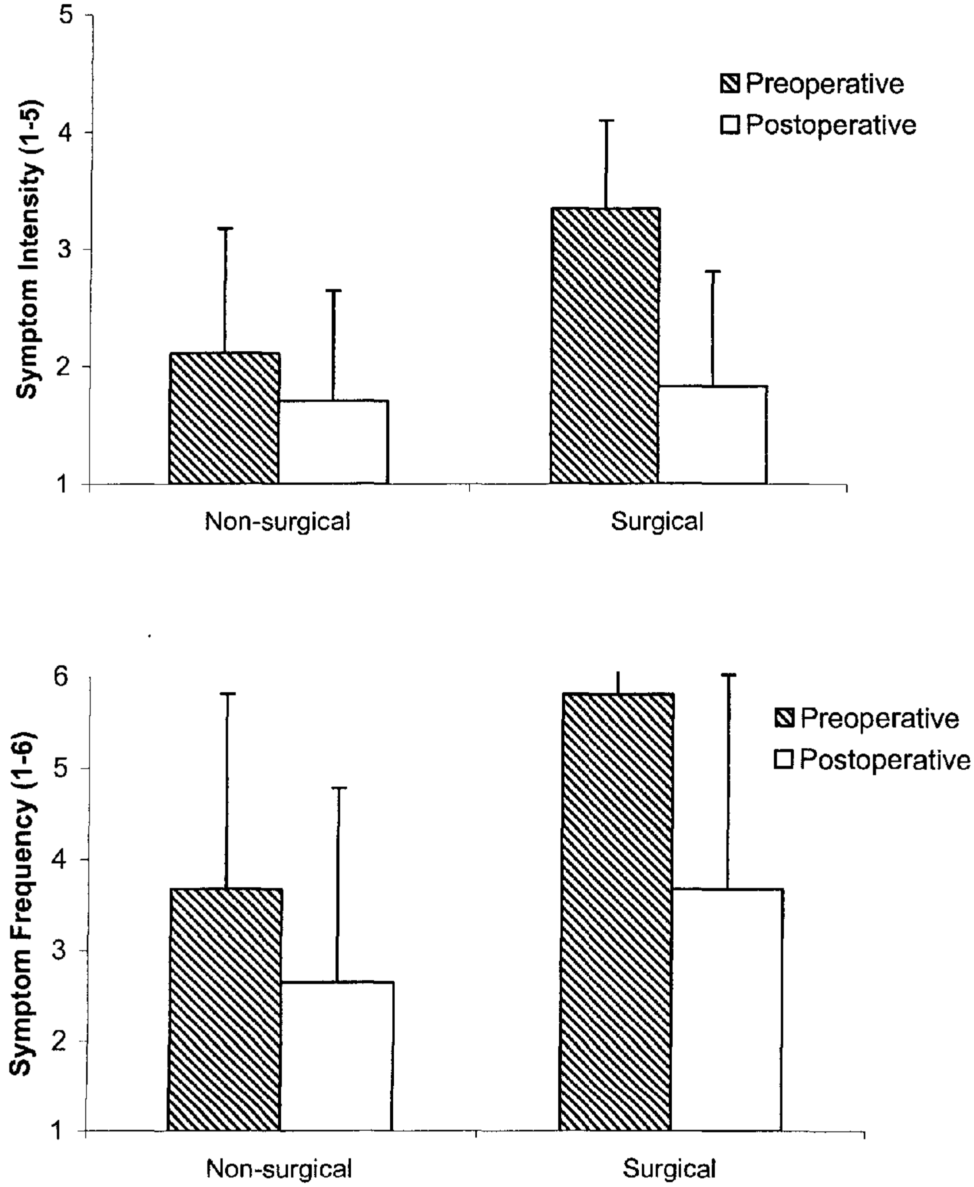

Figure 3- Average (+1 SD error bars) preoperative and postoperative symptom intensity and frequency for surgical and non-surgical hands

List of Publications

Present:

Radwin, R. G., Salvi, F. J., and Sesto, M. E. "Analysis Tools for Musculoskeletal Impairments and Rehabilitation," Research Symposium, RESNA 2000 Conference, Orlando, FL June, 2000.

Sesto, M. E., Radwin, R. G., Salvi, F., and Manning, R., "Worker Monitoring Tests for Carpal Tunnel Syndrome," *International Ergonomics Association XIVth Triennial Congress and Human Factors and Ergonomics Society 44th Annual Meeting,* San Diego, CA, August, 2000.

Sesto, M. E., Radwin, R. G., Zachary, S. V., Rockhill, B. J., and Harm, C. J., "Tests for Quantifying Recovery Following Carpal Tunnel Surgery," *Human Factors and Ergonomics Society 45th Annual Meeting,* Minneapolis, MN, October, 2001.

Sesto, M. E., Radwin, R. G., and Salvi, F. J., Functional deficits in carpal tunnel syndrome, *American Journal of Industrial Medicine*, 44(2),133-40, 2003.

Anticipated:

Radwin, R. , Sesto, M. E, and Zachary, S. V., Functional tests for quantifying recovery following carpal tunnel surgery, Submitted to *Journal of the American Medical Association.*