Functional Deficits in Carpal Tunnel Syndrome

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Background *Carpal tunnel syndrome (CTS) is a major occupational illness in the US. The Wisconsin Test is a quantitative computer-controlled test battery designed for measuring sensory and psychomotor function. Subjects were recruited from industrial jobs at high-risk for CTS to determine if subtle sensory and motor deficits were observable in a working population. Outcomes were studied for potential use as an injury surveillance instrument.*

Methods *A total of 208 subjects participated (72 males and 136 females). Participants completed a symptom survey, were given a physical examination, administered nerve conduction tests, and were tested using the Wisconsin Test battery.*

Results *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).*

Conclusions *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 CTS corresponds with functional psychomotor and sensory impairments measured in these tests.* Am. J. Ind. Med. 44:133–140, 2003.

KEY WORDS: carpal tunnel syndrome; injury surveillance; nerve conduction test; functional test; psychomotor test; sensory test; work related musculoskeletal disorders

INTRODUCTION

Carpal tunnel syndrome (CTS) continues to be one of the most prevalent peripheral entrapment neuropathies, and is a major cause of reported occupational illness in the US [Phalen, 1972; Bureau of Labor Statistics, 1999]. Astroshi et al. [1999] estimates that the prevalence of CTS which was clinically and electrophysiologically confirmed in the general population is 2.7%. 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

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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 [Jeng et al., 1994; Radwin 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., 1994, 1997a]. The sensory test involves actively probing a computer-controlled gap in a highly polished surface [Radwin et al., 1994; Jeng and Radwin, 1995] 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,b]. 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. This non-invasive test battery can be administered in as little as 15 min 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 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 I. The maximum number of participants tested in each company was limited to 60 in order to distribute subjects among various industries.

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 gave their informed consent. Participants were paid their regular hourly salary; 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.

TABLE I. Test Site and Industrial Worker Distribution, Midwestern United States

		Number of subjects				
Company	**Industry**	**Male**	**Female**	**Total**	**Age (years)[a]**	**BMI[a,b]**
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		

[a]Mean and (SD).
[b]Body-mass index (BMI).

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 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 (NCS)

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 3 cm 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°C.

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 5 s 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 5 s and average force from the 2nd to 4th s 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 0.6 ms. 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 CTS.

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 ($P < 0.05$) for some of the functional test variables. Sixteen subjects (32 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

To date, 208 subjects (416 hands) have been tested, including 72 males and 136 females. The average age was 38.4 years (SD = 9.2) and the age range was 18–60 years. The ethnicity was predominantly white, not of Hispanic origin (n = 181). These demographic distributions were consistent for all of the participating plants.

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/s ($F(1, 277) = 3.80$, $P = 0.05$). 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 ($F(1,283) = 5.10$, $P < 0.05$) (Table II). 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.

TABLE II. Ten Percent Pinch Rate for Hands Categorized by Positive and Negative Symptoms (Sx), Nerve Conduction Study (NCS), and Physical Exam (PE) of Industrial Workers

	Sx		NCS[a]		PE[b]	
	−	+	−	+	−	+
Number of hands	199	69	233	47	220	66
Pinch rate (pinches/s)						
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

[a] $P = 0.05$.
[b] $P = <0.05$.

Combined Criteria for a Case

Subjects were classified based on combined outcomes of physical exam, symptom survey, and NCS findings (Table III). 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 ($F(1, 261) = 2.86$, $P < 0.05$) and $F_{upper} = 10\%$ MVC overshoot ($F(1, 261) = 4.105$, $P < 0.05$). 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.

TABLE III. Functional Performance Variables for Physical Exam (PE), Symptoms (SX) and Nerve Conduction Studies (NCS) of Industrial Workers

	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)	0.15 (0.12)	169	0.14 (0.10)	92	0.16 (0.11)	22	0.21 (0.16)	35
20% Pinch rate (pinches/s)	4.96 (1.58)	157	4.64 (1.41)	84	4.87 (1.16)	22	4.35 (1.17)	35
10% Pinch rate (pinches/s)[a]	5.71 (1.74)	141	5.60 (1.90)	77	5.68 (1.10)	19	4.20 (1.34)	29
10% Overshoot (%MVC)[a]	25.32 (21.81)	141	22.48 (21.00)	77	21.85 (17.23)	19	41.38 (26.00)	29
Pinch rate difference (pinches/s/%MVC)	−0.1386 (0.3008)	119	−0.1929 (0.1954)	67	−0.1145 (0.2748)	18	−0.0056 (0.2419)	24

[a] $P < 0.05$ (univariate analysis 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); MVC, maximum voluntary contraction.

Clinical Criteria for a Case

A strict clinical case definition of CTS 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 IV). The average gap detection threshold for the +CTS group was 0.21 mm while the −CTS group gap detection threshold was 0.15 mm ($F(1, 331) = 5.52$, $P < 0.05$). The average gap detection threshold for the +CTS group required a 40% larger gap than the −CTS group.

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/s ($F(1, 205) = 4.09$, $P < 0.05$). 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 ($F(1, 175) = 4.51$, $P < 0.05$). The −CTS group average change in pinch rate was −0.1578 pinches/s/%MVC while the +CTS group was −0.0056 pinches/s/%MVC. This represented a 96% difference between the two groups.

Statistically significant demographic differences were observed between the +CTS and −CTS groups for age ($F(1,369) = 17.98$, $P < 0.001$) and body mass index (BMI) ($F(1,355) = 24.06$, $P < 0.001$). The +CTS group had a mean age of 43.12 years (SD = 8.87) and a mean BMI 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 ($P < 0.05$) differences between +CTS and −CTS groups. The canonical discriminant function coefficient was 0.15 mm for the gap detection threshold (sensitivity = 0.49 and specificity = 0.69), 5.5 pinches/s 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/s/%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 [Kimura, 1989; Dawson, 1990; Rempel et al., 1998]. Studies where subjects are classified as +CTS or −CTS based on symptom reports alone may systematically misclassify disease status [Gerr et al., 1995]. Although this combination of criteria is recommended, there is no universally agreed criterion for diagnosis of CTS [Homan et al., 1999]. 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

TABLE IV. Functional Performance Variables for +CTS and −CTS Groups of Industrial Workers

	−CTS		+CTS	
Variable	**Mean (SD)**	**N**	**Mean (SD)**	**N**
Gap detection threshold (mm)[a]	0.15 (0.11)	299	0.21 (0.16)	35
20% Pinch rate (pinches/s)	4.85 (1.48)	283	4.36 (1.17)	35
10% Pinch rate (pinches/s)[a]	5.69 (1.73)	254	4.20 (1.34)	29
10% Overshoot (%MVC)[a]	23.86 (20.81)	254	41.37 (26.00)	29
Pinch rate difference (pinches/s/%MVC)[a]	−0.1578 (0.2651)	220	−0.0056 (0.2419)	24

CTS, carpal tunnel syndrome.
[a] $P < 0.05$.

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 and were classified as cases by an occupational health nurse, while individuals reporting no symptoms were classified as controls [Jeng et al., 1997b]. In the current study, volunteers were selected based solely on their job. 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 selection. In those studies, the extremes of the distribution of CTS 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 CTS. 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 10 min 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 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. [1997b] found that electrodiagnostic methods for predicting future CTS 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,b]. Demographic differences between cases and controls were also observed. The +CTS group was older in age and had an higher BMI than the −CTS group. Werner et al. [1997a] 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 CTS 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 ($F(1, 146) = 4.35$, $P < 0.05$, $F_{upper} = 10\%$ pinch rate $F(1, 116)=3.86$, $P = 0.05$ and change in pinch rate ($F(1, 95) = 7.68$, $P < 0.01$). The magnitude of differences (26–96%) 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 investigations 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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