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Carpal tunnel syndrome (CTS) is one of the fastest-growing occupational illnesses in the United States. Workers in the meat packaging, newspaper, poultry, textile, and electronics industries suffer from incidence rates as high as 20 to 50 percent per year. The costs associated with this syndrome range from $3500 to $30,000 per case in workers' compensation and medical costs. While numerous occupational and nonoccupational risk factors are known to be associated with CTS, no quantitative thresholds are known to exist. This nested cross-sectional study was designed to determine occupational and nonoccupational risk factors associated with CTS and to develop a predictive linear equation for tendinitis and CTS among the hands of solder touch-up workers in the electronics assembly industry. Subjects were employees of an electronics manufacturing company performing solder touch-up activities on printed circuit boards. Each received a questionnaire, a limited physical examination of the extremities by an occupational physician, and a detailed evaluation of work methods over a standardized series of work tasks. Data collected were used to draft a predictive equation using multivariate statistical techniques including factor analysis, discriminant analysis, and multiple logistic regression. The draft equation was tested on workers for whom the same measurements were collected at a similar yet different workplace from the same employer. By combining the data from both sites, a final equation was developed and its predictive accuracy evaluated. Results indicate that (1) interemployee differences in work practices are important determinants of CTS risk, (2) equations can predict whether or not the hands of exposed workers are likely to have tendinitis or CTS by applying measurements of currently accepted risk factors, (3) work-related risk factors appear to be more important than nonoccupational risk factors such as age and obesity in predicting whether a hand is likely to have CTS or not, and (4) interactions between occupational risk factors (angles and frequencies) are important predictor variables. LYNCH, R.M.; MOHR, S.N.; GOCHFELD, M.: PREDICTION OF TENDINITIS AND CARPAL TUNNEL SYNDROME AMONG SOLDERERS. APPL. OCCUP. ENVIRON. HYG. 12(3):184–189; 1997. © 1997 AIH.

Cumulative trauma disorders (CTDs) are "disorders of the muscular and/or tendinous and/or osseous and/or nervous system(s), caused, precipitated or aggravated by repeated exertions or movements of the body."(1) Carpal tunnel syndrome (CTS) is one of the most severe CTDs of the upper extremities. It occurs as a result of entrapment and compression of the median nerve as it passes through the wrist into the hand, which can result in pain, numbness, weakness, and loss of grip strength in the affected hand. There are two prominent approaches to characterizing this nerve compression: mechanical compression of the median nerve, resulting from inflammation of surrounding tendons; and microvascular insufficiency of vessels servicing the area.(2) While CTS is one of the most severe CTDs of the hand and wrist, tendinitis (a less severe condition due to inflammation of the tendons) is often reported among employees performing hand-intensive activities.

The National Institute for Occupational Safety and Health surveillance definition of CTS is the following:

- one or more symptoms of pain, numbness, or increased or decreased sensation affecting any of the median nerve distributions,
- objective findings of CTS in the affected hand or wrist (e.g., positive Tinel's, Phalen's, or pin prick, or evidence of nerve conduction slowing via electrodiagnostic studies), and
- evidence of work relatedness.(3)

CTDs comprised approximately 60 percent of the occupational illnesses reported to the U.S. Bureau of Labor Statistics between 1990 and 1992, with CTS comprising approximately one-third of the CTDs (or 20% of all occupational illnesses) in 1992.(4)

The common occupational risk factors for CTS include repetitive movements of the wrists or fingers with loading of the tendons in the carpal tunnel, forceful contractions of these tendons, extreme flexion or extension of the wrist, pinching or other awkward postures, mechanical stresses over the median nerve, exposure to vibration, and use of poorly fitting gloves.(5) Despite the numerous studies conducted to date describing these general risk factors, no quantitative exposure thresholds have yet been established.(1)

Yet workplace factors are not responsible for all cases of CTS. One general population prevalence study estimated that as much as 9.3 percent of the population of The Netherlands may have detected and undetected CTS irrespective of occupational factors.(6) Commonly reported nonoccupational risk factors include rheumatoid arthritis, gout, diabetes, pregnancy, use of oral contraceptives, and obesity.(7,8) Nonoccupational activities such as musical instrument use and other hobbies are also associated with CTS.

Objectives

The first objective of this study was to determine whether the published occupational and nonoccupational risk factors for CTS are applicable to solderers in the electronics assembly industry, and which of those risk factors were most highly associated with CTS. Because printed circuit board (PCB) repair is such a complex and varied job, the second objective of this study was to determine if job task measurements over a variety of tasks could be used to accurately estimate the risk of CTS. The third objective was to determine if the risk factors could be measured, quantified, and analyzed to provide a predictive equation indicating which combination of work habits and/or personal attributes discriminates between normal hands and hands of employees likely to have CTS and tendinitis at two distinct work sites where similar work tasks are performed.

Experimental Design

This study was designed as a multisite, cross-sectional study with nested cases and controls. Two work sites from a large computer manufacturer where employees perform PCB repair operations in the electronics assembly industry were selected for this study. Based on employee and management interviews, the major job tasks performed by the solder touch-up repair employees (and therefore evaluated for this study) include: (1) soldering leads, (2) removing solder from PCB holes, (3) removing solder bridges from PCBs, (4) cutting foils, and (5) clipping leads. The work described above requires numerous awkward wrist postures known to be risk factors for CTS and represents major components of the work performed by these employees. For each work site, all of the full-time solder touch-up employees—19 employees at site 1 and 18 at site 2—were evaluated using the following:

- written survey instrument for each at-risk employee
- employee indication of pain on a diagram of the hand
- limited physical examination
- grip strength testing
- job task measurement and videotaping for each employee.

Written Survey Instrument and Hand Diagram

At both work sites, all workers performing PCB repairs were considered to be at risk for developing CTS, and were administered a written questionnaire to determine length of employment, length of work in the current job title, medical history of gout, diabetes, arthritis, acute wrist trauma, oral contraceptive use, and other demographic information. These employees indicated subjective feelings regarding wrist pain on the survey instrument. Questions regarding any previous medical diagnosis for CTS or overuse syndromes, workers' compensation history, acute wrist injury, and leisure activities potentially contributing to CTS were also included. Additionally, the survey included information regarding employee personality styles, work habits, and stress. Symptom survey questions were adapted from Anderson.[9]

To assist in interpreting any reports of pain indicated on the survey instrument, all employees were requested to indicate the location(s) of hand pain (if any) on a dorsal and palmar hand diagram. Katz *et al.*[10,11] found a 96 percent sensitivity for patients demonstrating a "probable or possible" CTS rating and a 91 percent specificity for patients demonstrating an "unlikely" rating when such diagrams were combined with a limited examination by a physician, thus eliminating the need for costly electrodiagnostic studies.

Limited Physical Examination

All subjects were evaluated by an occupational physician blind to the results of the workplace variable measurements. The physician performed Tinel's, Phalen's, Finklestein's, two-point discrimination, and other tests seeking signs and/or symptoms of CTDs of the hands and wrists, including tendinitis and CTS, as well as tests to identify CTDs of the arm, shoulders, and neck. Body height and weight were also measured for each employee.

Strength Testing

The physician conducted strength tests on each employee to determine maximum grip and pinch strength in the dominant hand using a Jamar hand dynamometer and pinch dynamometer, respectively. Following this, the physician estimated the strength requirements necessary to perform the work of holding the soldering iron by asking the employee to squeeze the pinch dynamometer as tightly as they squeeze the soldering iron. The procedures for obtaining these measurements were adapted from the work of Caldwell *et al.*[12] and Chaffin.[13] Using these data, the percent of each employee's maximum voluntary contraction necessary to perform the soldering iron job was estimated.

Job Exposure Measurements

The variables indicated below were measured for each employee performing the five tasks described earlier by a certified industrial hygienist who was blind to the findings of the physician.

- Frequency of repetition—measured in repetitions per minute. The directionality of repetitions was also determined; specifically, flexion/extension repetitions, ulnar/radial repetitions, pronation/supination repetitions, and finger (not wrist) repetitions.
- Force—estimated as the percent maximum voluntary contraction for the soldering iron as measured by the physician.
- Wrist position—The angle of static wrist deviation in each of the flexion, extension, ulnar, radial, and pronation/supination directions was measured using a hand goniometer according to the techniques contained in Engleberg.[14]
- Mechanical pressure on median nerve—Any job during which direct pressure on the mid-region of the palm or wrist occurred was considered to be positive for mechanical compression.

These measurements were collected while each subject performed a standardized series of repairs on a standard PCB involving the five tasks described to be the most common types of repairs. This method was used to eliminate measurement differences between subjects due to any particular type of repair occurring at the time of data collection. Each subject was videotaped for approximately 15 minutes during the collection of the above-referenced data. The order in which subjects were evaluated was opportunistic. Subjects were videotaped from an upper-lateral position with the majority of the torso in view. Emphasis of the videotaping was on the arm and wrist. The videotape was reviewed to determine repetition rates and postures.

Classification of Cases

Hands were classified as normal, tendinitis, or CTS based on the results of the symptoms reported, hand diagram indications, and physician's evaluation. Normal hands were designated as controls; tendinitis and CTS hands were designated as cases.

Statistical/Epidemiological Methods

Cases and controls from both work sites were analyzed by work site for the contribution of age, gender, obesity (measured as body mass index), years of employment in current job title, and predisposing medical conditions, as well as job task variables on hand status (normal, tendinitis, or CTS). Standard univariate statistics were utilized (i.e., Chi-squared, *t*-tests) to determine individual variable associations with tendinitis or CTS.

Multivariate statistical methods were used to determine correlations between multiple risk factors and hand status. Factor analysis using the principal components extraction with varimax rotation was used to determine independent variable associations. Discriminant analysis determined groupings and predictive equations for normal versus tendinitis- and CTS-diagnosed hands. The model building approach used in the discriminant analysis included a forward stepwise procedure with a predictor variable selection criterion to minimize Wilks' Lambda, and an F statistic greater than 1. Prior probabilities were set at 0.5, and classification was based on the pooled within-groups covariance matrix. Data analysis was performed using the SPSS PC+ statistics software.

Multiple logistic regression was performed using the Personal Computer Statistical Analysis Software to generate a predictive equation for the combined sites data, determine critical cutoff values for the variable measurements, and ensure that findings were not method dependent. Odds ratios were determined using the multiple logistic regression technique. In building the multiple logistic regression model, the techniques described by Hosmer and Lemeshow[15] were used, including forward stepwise selection of base logistic model variables (entry/exit criteria, $p = 0.2$) with additional variable forced entry testing ($p = 0.3$). Model inclusion was based on reducing the -2 log likelihood value.

Because each hand of an employee has a unique exposure (and potentially a different diagnosis), all univariate and multivariate analyses were performed on individual hand records.

Results

Site 1

One hundred percent of the full-time solder touch-up employees at site 1 were evaluated (total of 38 hands from 19 solderers). All of the solderers were female with a minimum of 25 years of work experience with the company. The age ranged from 42 to 67 years, with an average age of 52 for the cohort. Approximately 42 percent of the workers were obese (body mass index > 30). All workers at site 1 indicated right hand dominance. Nine of the subjects (47%) had normal hand examinations for both hands. One subject (5%) had tendinitis in both hands, and three subjects (16%) had bilateral CTS. The remaining 32 percent of subjects showed differing status in each of their hands.

TABLE 1. Hand Status from Physical Examination: Site 1

	Normal	Tendinitis	CTS	Total
Left	11 (29%)	3 (8%)	5 (13%)	19
Right	11 (29%)	3 (8%)	5 (13%)	19

Fifty-eight percent of the hands were classified as normal, 16 percent were classified as tendinitis, and 26 percent were classified as CTS. Table 1 shows a breakdown of hand status for each hand.

Employer medical records for 1990 to 1993 indicated that a total of 18 upper extremity complaints were recorded from the pool of full-time employees covered under this study. Six were related to hands and wrists, with three claims involving lost-time and workers' compensation expenditures ranging from $200 to $37,000.

Solder touch-up work involves static postures with very slight wrist or finger movements necessary to raise and lower the soldering iron from the PCB. These slight wrist or finger movements have been dubbed microrepetitions for this study. Approximately 76 percent of the hands at site 1 were measured to be working with the wrist in extension more than an average of 25 degrees. Eighty-four percent of the hands also worked with a radial or ulnar deviation, and 60 percent of the hands were pronated or supinated more than 25 degrees. Approximately 24 percent of the workers indicated through strength testing that their pinch strength requirements for the soldering iron were between 21 and 50 percent of their maximum voluntary contraction. The average maximum pinch strength for the workers in this cohort was 16.2 pounds, with

TABLE 2. Associations Between Variables and Tendinitis or CTS: Site 1

Variables	Chi² Sig.	*t*-Test	Risk Dir.
Nonoccupational variables			
Age versus T/CTS	0.33	0.09*	Increase
Body mass index versus T/CTS	0.24	0.08*	Increase
Time off versus T/CTS	—	0.04	Increase
Arthritis, etc. versus CTS	—	0.15*	Increase
Family income versus T/CTS	—	0.19	Decrease
Occupational variables			
Flex/extension versus CTS	0.18	0.10	Decrease
Radial/ulnar versus CTS	—	0.22	Decrease
Pronate/supinate versus T/CTS	0.16	0.11	Increase
Finger micromovements versus T/CTS	0.05	0.02	Decrease
% Max. contraction versus T/CTS	0.09	0.31	Increase
Cycle frequency versus CTS	0.06	—	Increase

T = tendinitis; T/CTS = tendinitis and CTS considered as a single outcome.
*One-tailed test significance due to suspected direction of effect. All other tests were two tailed.

TABLE 3. Predictive Equation: Site 1

Variable	Coefficient	Explanation
Variables positively associated with CTS and tendinitis		
UNEXP3	+0.92536	>30 days off during past 3 years
PRODCMSA	+0.68596	Total wrist angle times average cycle frequency
MRY	+0.55630	Radial/ulnar microrepetitions
MRX	+0.43181	Flexion/extension microrepetitions
SUMANGLE	+0.38592	Sum of average wrist angle
Variables inversely associated with CTS and tendinitis		
MRST	−0.34936	Finger microrepetitions (not wrist)
MRSQZ	−0.43769	Squeeze microrepetitions (plier use)
AVRADUL	−0.51033	Average radial/ulnar deviation angle
FAMINC	−0.73964	Annual family income
PRODCMZ	−1.22383	Average pronation/supination angle times frequency

Variables with a positive sign preceding the coefficient increase with increasing risk of tendinitis and CTS. Larger coefficients represent stronger associations. Variables with a negative sign preceding the coefficient have an inverse relation to tendinitis or CTS.

the average maximum amount of force used in the soldering iron estimated to be approximately 4 pounds.

Table 2 shows the association between variables tested and tendinitis and/or CTS for hands at site 1, and suggests that several of the published risk factors may be applicable to employees in this cohort.

Factor analysis and discriminant analysis identified variables most highly associated with tendinitis and CTS. To account for possible interactions between measured variables (e.g., cycle frequency, average wrist angles, etc.), a series of derived interaction variables were calculated and made available for use by the factor and discriminant analyses.

Through these multivariate techniques, an equation was developed using the variables the computer determined to be most highly capable of distinguishing normal hands from hands having tendinitis or CTS at site 1. The variables comprising the equation, along with the standardized discriminant scores, are as shown in Table 3.

Prediction accuracy for site 1 hands was 73 percent for control hands and 94 percent for tendinitis and CTS (case) hands. Overall predictive accuracy of this equation was 82 percent.

Site 2

A total of 36 hands from 18 employees (100 percent) of the solder touch-up employees at site 2 were analyzed. Work experience ranged from <1 to 10 years. The population was 44 percent male and 56 percent female, ranging between 22 and 56 years of age. In addition to the substantial difference in job tenure, the following personal variables were significantly different among workers at the two work sites ($p < 0.03$): age, gender, stress, predisposing medical condition, family income, and body mass index. The differences with respect to predisposing medical condition and family income were expected to be due primarily to differences in age distributions. Older workers were also expected to have higher family income and more predisposing medical conditions such as arthritis. Body mass index was elevated among the site 2 workers as compared with the site 1 workers.

Of the 36 hands analyzed at site 2, 23 were normal, 6 were found to have tendinitis, and 7 were diagnosed as having CTS. This distribution was very similar to the distribution found at site 1 (Chi^2 p value = 0.78).

Average maximum pinch strength was 21 pounds, with

TABLE 4. Predictive Equation: Site 2

	Coefficients		
Variable	Function 1	Function 2	Explanation
UNEXP3	0.31306	1.20556	>30 days off during past 3 years
STRESS	−1.14704	−0.59916	Self-reported job stress
FAMINC	−0.16108	0.62962	Annual family income
MRX	1.52051	−0.21705	Flexion/extension microrepetitions
MRY	1.23879	−0.56050	Radial/ulnar microrepetitions
MRZ	0.98282	−0.53797	Pronation/supination microrepetitions
AVSTAT	−0.40960	0.96114	Finger micromovements (not wrists)
PRODREPS	−2.72418	−0.00402	Finger micromovements times cycle frequency
PRODCMX	0.72869	0.37703	Average flexion/extension angle times frequency
PRODCMY	0.70413	−0.51954	Average ulnar/radial angle times frequency

In function 1, positive coefficients indicate variables that increase with the risk of tendinitis or CTS versus normal hands. In function 2, negative coefficients indicate variables that increase with the risk of CTS versus normal or tendinitis.

average maximum force on soldering irons estimated to be 1.7 pounds—substantially different from the pinch strength and soldering iron forces at site 1. An analysis comparing wrist angles and cycle frequencies for employees working showed differences between the two sites for some of the work variables as well.

Using the same techniques described earlier, the most predictive equation utilized largely the same combination of occupational variables determined to be most predictive site 1. The best predictions were produced when tendinitis and CTS were not combined as a single outcome. Variables selected for the site 2 equations are found in Table 4.

None of the widely accepted personal risk factors (e.g., obesity, age, etc.) were strong enough predictors to enter the site 2 equations. Overall predictive accuracy of the equations was 86 percent, with 73 percent of the control hands, 100 percent of the CTS cases, and 100 percent of the tendinitis cases predicted properly.

Close examination revealed that the signs associated with some of the variables were opposite between the equations derived at the two sites. Analysis revealed that the sign differences were due to gender (being female was an effect modifier) and work practice differences between the sites. This analysis was complicated by the great gender disparity between the sites, and further research regarding gender as an effect modifier is suggested.

Analysis of Data from Both Sites Combined

The data from both work sites were pooled and analysis was repeated. A discriminant equation taking into account the combined data set from both sites was developed using the occupational variables common to individual and combined site analyses using the direct entry method of discriminant analysis. Multiple logistic regression was used as a means to ensure that the predictions were not method dependent, as well as to determine critical cutoff points from field measurement data. A final equation to predict CTS and tendinitis among the hands of solder touch-up employees at both sites was developed which accurately predicted approximately 70 percent of the hands from both sites (73.3% of the control hands and 65.5% of the tendinitis or CTS diagnosed hands). Table 5 displays the critical values and odds ratios for the variables identified in the above equation based on the multiple logistic regression model.

The final equation for this study was:

$$\begin{aligned} T/CTS = [&(PRODREPS* - 0.05) + (MRY*0.35) \\ &+ (AVRADUL*0.12) + (AVPROSUP*0.75) + (AVCM*1.1) \\ &+ (PRODCMX*0.006) + (PRODCMSA* - 0.06) \\ &+ (SUMANGLE*0.003) \\ &+ (SITE*2.4) + (GENDER* - 1.4) + (AGE*2.6) \\ &+ (MRX* - 0.28) - 8.6] \end{aligned} \quad (1)$$

where: if T/CTS < 0, then tendinitis or CTS is predicted.

TABLE 5. Critical Values and Odds Ratios for Variables in Tendinitis/CTS Prediction Equation: Combined Sites

Variable	Critical Value	Odds Ratio	95% CI
PRODREPS	—	1.05	0.84, 1.07
MRY	—	0.57	0.23, 1.4
AVRADUL	6 degrees	0.26	0.06, 1.1
AVPROSUP	22.6 degrees	0.18	0.04, 0.93
AVCM	12.25 c/m	0.21	0.03, 1.48
PRODCMX	247.2	0.35	0.09, 1.36
PRODCMSA	961.4	0.57	0.09, 3.67
SUMANGLE	41	3.1	0.45, 21.7
SITE	—	0.01	0.001, 0.47
GENDER	Female	4.3	0.65, 28.0
AGE	44 years	0.02	0.001, 0.47
MRX	—	1.7	0.58, 4.95

PRODREPS = average cycle frequency times the proportion of tasks where finger movements (not wrist movements) were used to raise and lower the tip of the soldering iron
MRY = proportion of radial/ulnar microrepetitions over the 5 tasks
AVRADUL = average angle of radial or ulnar deviation in degrees
AVPROSUP = average angle of pronation or supination in degrees
AVCM = average cycle speed of wrist movements over the five tasks
PRODCMX = average cycle frequency times the average flexion/extension angle
PRODCMSA = average cycle frequency times the summation of all average wrist angles
SUMANGLE = summation of average wrist angles measured in the flexion/extension, radial/ulnar, and pronation/supination planes
SITE = site 1 = 1, site 2 = 2
GENDER = sex of the subject (male = 1, female = 2)
AGE = age of the subject in years
MRX = proportion of flexion/extension microrepetitions over the five tasks

Discussion

As with all cross-sectional studies, information related to risk factors and hand status were collected simultaneously. This means that a cause/effect relationship between measurements and hand status cannot be assumed. It is possible that employees with tendinitis or CTS have modified their work habits as a means of pain management, resulting in skewed associations between measured work practices and positive hand status findings. It is also possible that some workers may have developed CTS before working for the current employer or as a result of non-work-related conditions or activities. Additionally, the possibility exists that employees may have unconsciously modified their work habits as a result of the investigator's presence. The findings of this study must therefore be considered as associative rather than causal. Because there were two records for each person, and due to the preponderance of obesity among study subjects, it is possible that the importance of nonwork variables was underestimated.

The highly accurate predictions suggest that minor differences in work practices between employees within a site can be used to predict tendinitis and CTS. It also suggests possible reasons why some employees performing a job may have hand problems and others do not. This has significant implications for proper tool design, work organization, and training.

The measurements used during this study were selected based on availability to industrial hygienists, safety professionals, and occupational nurses and physicians. No costly electrodiagnostic equipment was used, and the worksite measurements were collected using standard goniometers, stopwatches, and video equipment. Further development and refinement of the most important variables to reduce data collection to only the most essential measurements would advance efforts to simplify this technique.

Collecting measurements for all employees performing the tasks was essential to this study design. This, however, represents a shift from the manner by which ergonomic evaluations are often conducted (based on employee complaints only). The benefit of measuring and testing all employees is that previously undiagnosed cases of tendinitis and CTS may be discovered. Early diagnosis can result in early intervention and prevention of further exacerbation of health problems, yet it can generate employer concerns regarding increasing reported cases. Furthermore, hands with tendinitis can serve as early warning of potential CTS cases. Finally, work practices from controls are needed to establish a basis for evaluating the potential importance of work practices of persons with case hands.

Further research should enroll larger numbers of employees at additional sites to validate this methodology. Prospective studies should be considered wherein new employees without symptoms are followed to determine which work practices and/or personal risk factors are associated with the development of tendinitis and CTS.

Conclusions

Personal and occupational variables currently suggested within the scientific literature as risk factors are applicable to employees performing solder touch-up work in the electronics manufacturing industry. Excellent within-site predictive equations for CTS can be developed based on interemployee differences in work practices using combinations of accepted occupational risk factors. Microrepetitions of the wrist (very slight movements in the flexion/extension, ulnar/radial, and pronation/supination planes) are extremely important in predicting hand status; however, the work variables most highly associated with tendinitis and CTS were combinations of measured variables. The strongest predictor variables were the interactions of average cycle frequency with total wrist angle. Others were the summation of all wrist angles, microrepetitions in the flexion/extension plane, and the product of average cycle frequency times amount of wrist movement. Future studies of risk factors for CTS should consider these interactions.

Work-related risk factors were more highly associated with tendinitis and CTS than personal risk factors such as age, obesity, and predisposing medical conditions. If this holds true in future studies, it implies that effective workplace interventions to reduce the incidence of CTS may be possible.

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