THE DEVELOPMENT OF A RISK ASSESSMENT MODEL FOR CARPAL TUNNEL SYNDROME (CTS): A CASE-CONTROL STUDY

Heecheon You
Department of Industrial and Manufacturing Engineering
The Pennsylvania State University
University Park, Pennsylvania

A risk assessment model for CTS was developed from a case-control study consisting of two case- and one control groups: (1) 25 non-work related CTS patients (NW-CTS), (2) 22 work-related CTS patients (W-CTS), and (3) 50 healthy workers (HEALTHY) having had no CTS symptom history. Personal susceptibility, psychosocial stress at work, and ergonomic hazards were surveyed by using a questionnaire directed toward CTS (reliability of each scale ≥ .7). Three logistic regression models were developed and cross-validated for (1) W-CTS/HEALTHY, (2) NW-CTS/HEALTHY, and (3) CTS/HEALTHY, resulting in 89%, 84%, and 88% of correct classification performance, respectively. While the first two models include personal and ergonomic factors, the last model does only personal factors. This suggests that injury causation of NW-CTS patients be attributable mainly to their 'high' personal susceptibility to CTS rather than exposure to adverse work conditions, while for W-CTS patients work exposure and/or personal susceptibility cause their injury.

INTRODUCTION

Carpal tunnel syndrome (CTS), a focal neuropathy of the median nerve at the wrist, has been a major problem in industry, especially with regard to those jobs involving repetitive use of the hand. Along with changes in nerve conduction, CTS symptoms include numbness in fingers, pain in gripping, feeling of pins and needles (or tingling) at the hand, reduced object control precision, decreased grip strength, and nocturnal awakening (Nathan and Keniston, 1993).

Epidemiological and experimental research has revealed personal attributes, psychosocial stressors, and physical work hazards contribute to the development of CTS. However, little is known regarding their relative contributions to the CTS development, exposure-severity relationships, and acceptable exposure limits for manual work to prevent workers from incurring CTS.

This study was intended to develop a risk assessment model that (1) predicts the likelihood of developing CTS for an individual having certain personal characteristics and being exposed to certain occupational hazards and (2) describes relative contributions of CTS risk factors.

MATERIALS AND METHODS

Case-Control Study Design

A case-control study was designed consisting of three groups: (1) 25 non-work related CTS patients (NW-CTS), (2) 22 work related CTS patients (W-CTS), and (3) 50 healthy workers (HEALTHY). Individuals identified in the EMG laboratory at Penn State Geisinger's Hershey Medical Center as having CTS based on both symptoms and standard nerve conduction studies participated in this study for the CTS case groups. The CTS patients were classified into one of the case groups according to the type of insurance covering their medical costs: health insurance for NW-CTS and workers' compensation insurance for W-CTS.

Two selection criteria were applied to the study groups: working experience for all the participants and CTS symptom history for the controls. Any individual who is not employed or whose working experience on the current job is less than one year were not recruited for three reasons: (1) individuals with less than one year of experience on the current work may provide insufficient information of occupational exposure, (2) the functional status of their hands may be better explained by the past job exposures rather than current job risks, and (3) NIOSH uses the 'previous year' criterion in defining work related musculoskeletal disorders (Kasl and Amick, 1996). Last, only workers without a medical history of CTS were considered for HEALTHY; their present condition of the hands/wrists were screened for the nerve injury by using the CTS Symptom Severity questionnaire (You et al., 1999). This study has been approved by the Institutional Review Board at the medical center.

The present study assumes distinctive hypothetical features for each study group regarding personal susceptibility to CTS, psychosocial stress, and physical hazards at work (Figure 1). Most NW-CTS patients are highly susceptible to CTS and most W-CTS patients moderately susceptible compared to healthy workers. Exposure to physical and psychosocial risks is higher in the W-CTS group than in both the NW-CTS and HEALTHY groups and the distributions of the NW-CTS and HEALTHY groups for psychosocial and physical exposure are similar each other.

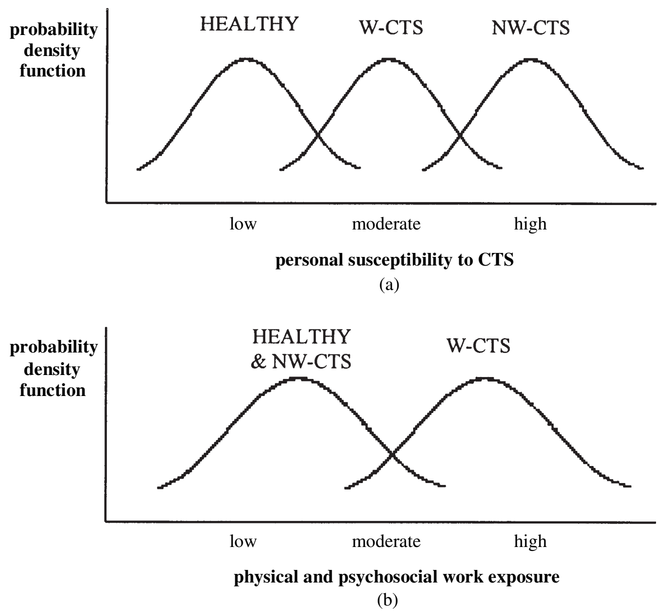


Figure 1. Hypothetical characteristics of personal susceptibility, physical and psychosocial work exposure for case and control groups: non-work related CTS patients (NW-CTS), work-related CTS patients (W-CTS), and healthy workers (HEALTHY).

Risk Assessment Questionnaire

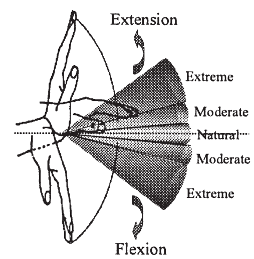
A risk assessment questionnaire tailored to CTS was developed in the present study: (1) personal susceptibility, (2) psychosocial stress at work, and (3) physical work hazards. All the factors included in the questionnaire, illustrated in Figure 2, are those having experimental or epidemiological evidence of a significant relationship with the risk of CTS. The assessment questionnaire includes 106 risk scales (63 personal factors, 7 psychosocial factors, and 36 physical factors); part of the scales are commonly accepted such as the Bortner scales (Bortner, 1969), Edinburgh Handedness Inventory (Kucera, et al., 1989), and psychosocial scales by Kasl and Amick (1996) and the rest are created in this study.

A test-retest study was conducted for 20 participants (9 CTS patients and 11 healthy workers) to ensure the reliability of each risk scale ≥ .7. Test and retest for each individual were administered at least one week apart. In case scales did not meet the minimum reliability requirement, their resolution was manipulated to increase their reliability and then cross-validation was performed; if the modified scales could neither satisfy the reliability requirement nor be validated, they were removed from the risk factor pool.

1. **Daily Hours of Work** ___8___ *hours/day*

2. **Daily Hand-Wrist Use**

	Right hand						
	Almost never (< 1%)	Rarely (1-10%)	Occa-sionally (11-20%)	Often (20-40%)	Frequently (40-60%)	Most of the time (60-80%)	Almost always (> 80%)
No use of the hands	☐ 1	☑ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
Use of the hands	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☑ 7



3. **Wrist Flexion/Extension**

	Right hand						
	Almost never (< 1%)	Rarely (1-10%)	Occa-sionally (11-20%)	Often (20-40%)	Frequently (40-60%)	Most of the time (60-80%)	Almost always (> 80%)
Use of the hands	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☑ 7
Natural (within 5 degrees)	☐ 1	☐ 2	☐ 3	☑ 4	☐ 5	☐ 6	☐ 7
Moderate (5 to 30 degrees)	☐ 1	☐ 2	☐ 3	☑ 4	☐ 5	☐ 6	☐ 7
Extreme (above 30 degrees)	☐ 1	☐ 2	☑ 3	☐ 4	☐ 5	☐ 6	☐ 7

Figure 2. Illustration of the CTS risk assessment questionnaire - questions of physical risk assessment.

Risk Assessment Survey Administration

The CTS risk assessment survey was administered individually in a secure room at the medical Center for the patients and at participating companies for the healthy workers. After giving informed consent, the participants completed the questionnaire with assistance of the investigator. The survey time varied from 40 min. to 1.5 hrs.

During survey, objective instruments such as anthropometers and hand- and pinch-grip dynomometers were provided for better assessment of body dimensions of interest and grip forces. Their participation was compensated.

RESULTS

Reliability Evaluation of Risk Scales

Spearman rank correlation coefficients were computed for the 106 risk scales by using the 20 test-retest data. Fourteen scales (two personal, four psychosocial, and eight physical scales) failed to meet the minimum reliability condition; among them, six modified scales (two personal, one psychosocial, and three physical scales) met the reliability requirement and also were cross-validated; the rest could not improve their reliability and thus were excluded.

Risk Factor Screening

Selection of risk factors from the 100 reliable risk scales was conducted to develop a parsimonious and stable model. Multiple logistic regression was conducted including a risk factor chosen, two stratification factors *age* and *gender*, and the interaction between *age* and *gender* for each of W-CTS, NW-CTS, and CTS (collective group of the two case groups) as case group and HEALTHY as control group (denoted as W-CTS/HEALTHY, NW-CTS/HEALTHY, and CTS/HEALTHY each). The inclusion of the two stratification variables in logistic regression was intended to enhance the accuracy of the parameter estimate of the selected risk factor.

Using the .25 level of significance as a screening criterion, 27 risk factors for W-CTS/HEALTHY, 21 risk factors for NW-CTS/HEALTHY, and 24 risk factors for CTS/HEALTHY were screened. These screened factors were further considered candidate variables to be included in risk assessment models.

Risk Assessment Model Development

With the screened factors, three multiple logistic regression models were developed by employing the forward stepwise algorithm with .15 and .20 as criterion probability of variable inclusion and removal from model, respectively: W-CTS/HEALTHY, NW-CTS/HEALTHY, and CTS/HEALTHY. Goodness-of-fit of each model was tested by the Hosmer-Lemeshow statistic at $\alpha = .05$ and all the models were found statistically appropriate. Each model includes a different set of risk factors as shown in Table 1; it is notable that no psychosocial and physical risk factors are included in the NW-CTS/HEALTHY model.

The logistic regression models provide information of the estimated coefficients (β), standard errors of coefficient

Table 1. Significant risk factors included in CTS risk assessment models

Risk Factors	Multiple Logistic Regression Models		
	W-CTS/ HEALTHY	NW-CTS/ HEALTHY	CTS/HEALTHY
Personal	1. gender (GENDER) 2. wrist ratio of the right hand (WR_R) 3. musculoskeletal disorder history during last 5 years at the hands/wrists (MD_5_D)	1. age (AGE) 2. gender (GENDER) 3. behavioral pattern-hard driving and competitiveness (HD) 4. weight (WT) 5. wrist ratio of the right hand (WR_R)	1. age (AGE) 2. gender (GENDER) 3. light of use of the hands/wrists for recreational activity (LU) † 4. weight (WT) 5. wrist ratio of the right hand (WR_R) 6. musculoskeletal disorder history during last 5 years at the hands/wrists (MD_5_D)
Psychosoical	-	-	-
Physical	1. use of heavy power grip forces (>20 lbs.) of the dominant hand (PW_20_D) 2. use of heavy pinch grip forces (>5 lbs.) of the dominant hand (PC_5_D) 3. very highly repetitive motions (<1 sec./operation) of the dominant hands (RE_1_D)	-	1. use of heavy pinch grip forces (>5 lbs.) of the dominant hand (PC_5_D) 2. very highly repetitive motions (<1 sec./operation) of the dominant hands (RE_1_D) 3. exposure of the hands/wrists to extremely cold temperature (<50 deg. F) (CO_E)

† The estimated odds ratios were less than 1, which indicates that workers who spends only minimal time (less than 1 hr/week) doing recreational activities of light use of the hands/wrists are at a higher risk of CTS than those who are actively involved in these recreational activities.

(SE β), odds ratios (OR), and 95% confidence intervals (CI) of OR. For example, the logistic regression model shown in Table 2 was developed for CTS patients as cases and healthy workers as controls (CTS/HEALTHY). This table indicates: (1) those who are old, females, having a square type of wrist, and having muscuoskeletal disorders at the hands/wrists during last five years are significantly at an increased risk to CTS; and (2) work involving heavy pinch grip forces, highly repetitive hand motions, and exposure to cold temperature increases the risk of CTS.

Table 2. Risk assessment model for CTS/HEALTHY (cases: CTS patients; controls: healthy workers).

Risk Factors	CTS / Healthy						
	Coefficient β	Standard Error se(β)	*p*	Partial Correlation *r*	Odds Ratio exp(β)	95% CI	
Age (AGE)	0.08	0.042	**0.06**	0.11	1.08	1.00	1.18
Gender (GENDER)							
Light use of the hands and wrists for recreational activity (LU)			0.12	0.04			
Minimal (<1 hr/week)	1.88	0.941	0.05	0.12	6.57	1.04	41.53
Low (1-3 hrs/week)	1.09	0.847	0.20	<.01	2.99	0.57	15.71
High (> 3 hrs/week)					1		
Weight (WT)	0.01	0.008	0.18	<.01	1.01	0.99	1.03
Wrist ratio - right hand (WR_R)	0.32	0.106	**<.01**	0.23	1.37	1.12	1.69
Musculoskeletal disorder during last 5 years at the hands and wrists (MD_5_D)	2.76	0.933	**<.01**	0.22	15.76	2.53	98.01
Use of heavy pinch grip forces (>5 lbs) of the dominant hand (PC_5_D)							
Very highly repetitive motions (<1 sec./operation) of the dominant hand (RE_1_D)			**0.09**	0.05			
Minimal (<.5 hr/day)					1		
Low (.5-1 hr/day)	3.80	1.709	0.03	0.15	44.61	1.57	1270.99
Moderate (1-2 hrs/day)	0.61	1.310	0.64	<.01	1.84	0.14	23.92
High (> 2hrs/day)	1.38	0.836	0.10	0.07	3.99	0.77	20.55
Exposure of the hands and wrists to extremely cold temperature (<50 deg. F) (CO_E)			**0.03**	0.15			
Low (<.25 hr/day)					1		
Moderate (.25-.5 hr/day)	-0.94	1.244	0.45	<.01	0.39	0.03	4.49
High (>.5 hr/day)	2.86	1.193	0.02	0.17	17.50	1.69	181.21
Female by WT	0.01	0.005	0.13	0.05	1.01	1.00	1.02
Female by PC_5_D							
Female by Low (<1 hr/day)					1		
Female by High (>1 hr/day)	1.91	1.095	**0.08**	0.09	6.77	0.79	57.89

The coefficients of each model were used to compute the probability of belonging to the case group for each individual with certain personal attributes working under certain job conditions by Equation 1.

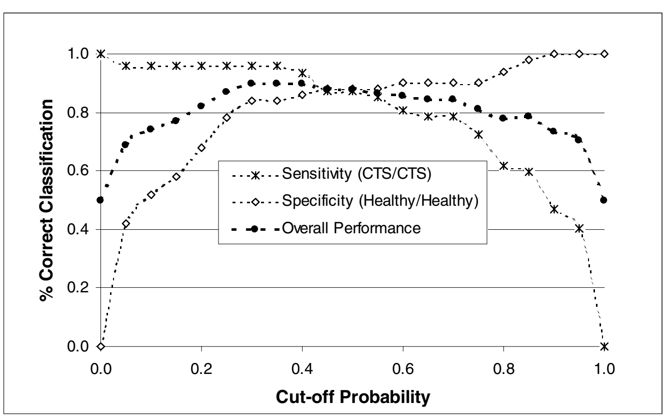
$$p = \frac{1}{1+e^{-(\alpha+\beta_1 X_1+\beta_2 X_2+...+\beta_p X_p)}} \quad \text{(Equation 1)}$$

Classification Performance of the Models

The logistic regression models provided information of probability for each individual of belonging to a group considered. To classify an individual based on probability, a cut-off criterion of probability (p_c) must be found.

The cut-off probability p_c of each model was determined considering the correct classification performance of the model. The performance of a classification model is represented in terms of sensitivity (% correct case classification such as P(CTS/CTS)) and specificity (% correct control classification such as P(HEALTHY/HEALTHY)). Depending on the location of p_c, the sensitivity and the specificity of logistic regression model vary each other in an opposite direction: an increase of sensitivity results in an decrease of specificity. Figure 3 demonstrates the variability of classification performance of the CTS/HEALTHY model along p_c. Choice of a cut-off probability between .45 and .50 resulted in 87% of sensitivity and 88% of specificity for the given data, which indicates both case and control groups are equally treated. Referring to the standard normal table, the detectability (*d'*) of the CTS/HEALTHY model was computed as 2.31 (*d'*=0, very poor; *d'*=2.33, nearly perfect).

Figure 3. Illustration of changes of sensitivity and specificity of the risk assessment model of CTS/HEALTHY depending on cut-off probability



Cross-Validation of the Models

Validation of the assessment models was conducted by following the *jackknife* method (Afifi and Clark, 1990). Multiple logistic regression was conducted repeatedly for 38, 37, and 50 subsets, created by excluding a single case randomly selected from the original data set, for W-CTS/HEALTHY, NW-CTS/HEALTHY, and CTS/HEALTHY, respectively. Then, prediction was made for each removed case by using the corresponding logistic regression model. The classification performance of each model varied within ± .10 from the original classification performance of the model.

DISCUSSION

The present study proposed a statistical protocol for CTS that could predict in which of case and control groups an individual having certain personal characteristics and being exposed to certain occupational hazards could be placed in the future. Based on a comprehensive literature survey (about 200 papers), this study identified personal, psychosocial, and physical risk factors having consistent evidence of a significant relationship with the risk of CTS. To survey a wide range of risk exposure information in an individual within a reasonable time, an assessment questionnaire directed toward CTS was developed and evaluated in terms of reliability-the degree of stability of subjects' reports from repeated assessments. About 25 risk scales, screened out of the 100 reliable risk scales by "pseudo" univariate logistic regression, were screened again by the forward selection algorithm of multiple logistic regression when developing the final assessment models. The three CTS risk assessment models showed between 84% and 89% of correct classification performance, between 2.02 and 2.51 of *d'* (good discriminability), and ± .10 of model stability. Thus this study supports the validity of the proposed protocol for CTS risk assessment.

In addition, this study supports a necessity of careful recruitment of participants, in CTS research, in terms of work-relatedness. It was hypothesized that injury causation for NW-CTS patients can be attributable mainly to their 'high' personal susceptibility to CTS rather than exposure to adverse physical and psychosocial work conditions, whereas for W-CTS patients the opposite should be concluded. In addition to this dichotomous causation, some portion of W-CTS patients might be explained by the combined contribution of personal susceptibility and work exposure. Our three logistic regression models (see Table 1) provided a support on the hypothesis. Thus, findings of previous CTS studies-most of which do not use rigorous selection criteria on the work-relatedness of CTS-investigating risk factors may include confounding of CTS patients' work-relatedness.

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REFERENCES

Afifi, A.A., and Clark, V. (1990). *Computer-aided Multivariate Analysis.* 2nd Ed., Van Nostrand Reinhold Co., New York: NY.

Bortner, R.W. (1969). A short rating scale as a potential measure of pattern A behavior. *Journal of Chronic Disease*, 22, 87-91.

Hosmer, D.W., and Lemeshow, S. (1989). *Applied Logistic Regression.* John Wiley & Sons, Inc.

Kasl, S.V., and Amick, B.C. (1996). Cumulative trauma disorder research: Methodological issues and illustrative findings from the perspective of psychosocial epidemiology. In *Beyond Biomechanics: Psychosocial Aspect of Musculoskeletal Disorders in Office Work.* Edited by Moon, S.D., and Sauter, S.L., Taylor & Francis Ltd.

Kucera, J.D.,and Robins, T.G., (1989). Relationship of cumulative trauma disorders of the upper extremity to degree of hand preference. *Journal of Occupational Medicine*, 31(1), 17-22.

Nathan, P.A., and Keniston, R.C. (1993). Carpal tunnel syndrome and its relation to general physical condition. *Hand Clinics*, *9*, 253-261.

Proctor R.W., and Van Zandt, T. (1994). *Human Factors: In Simple and Complex Systems.* Allyn and Bacon.

You, H., Simmons, Z., Freivalds, A., Kothari, M.J., and Sanjiv, M.J. (1999). Relationships between clinical symptom severity scales and nerve conduction measures in carpal tunnel syndrome, *Muscle & Nerve, 22*, 497-501.