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List of Terms and Abbreviations

CTS – Carpal Tunnel Syndrome

PE – Physical Exam

POPP – Post-offer, pre-placement

NCS – Nerve conduction studies

WC – Worker's Compensation

Abstract

Our study addresses two controversies concerning carpal tunnel syndrome (CTS), a common and costly disorder in working populations. One controversy concerns the relative contributions of work exposures and personal characteristics in the multi-factorial etiology of carpal tunnel syndrome. The second controversy concerns effective preventive strategies for CTS. Some have advocated pre-employment screening nerve conduction studies, with the rationale that these studies can predict future risk of developing carpal tunnel syndrome. Workers at higher risk for CTS can then be kept from jobs requiring intensive hand activity. Though screening for CTS is common, its effectiveness and the role of placement strategies in preventing carpal tunnel syndrome have not previously been studied in a prospective study. We conducted a prospective, longitudinal study of 1100 newly hired workers in a mixture of industries at increased risk for CTS. Baseline data included nerve conduction studies, a medical history, symptoms, physical examination, and job exposures. Workers were followed for 3 years through repeated questionnaires; a subcohort of more than 450 workers received more detailed follow-up, including repeat nerve conduction testing and observation of job exposures. Preliminary analyses from our study found that personal characteristics of obesity and age affected the risk of CTS. Past work exposures to force, vibration, and repetition also conferred a higher risk of CTS, even when controlled for age, obesity, and gender. While baseline nerve conduction studies did predict a higher rate of future CTS, the cost of screening all prospective employees outweighed likely costs savings that would result from not hiring workers with nerve conduction abnormalities. Most workers with abnormal baseline testing would not develop CTS, and most workers who developed CTS had normal baseline findings. Our study suggests that reducing workplace physical exposures is likely to reduce future risk of CTS, and that addressing other aspects of worker health such as reducing obesity may also prevent future cases of CTS. Pre-employment screening of workers with nerve conduction testing is unlikely to be a cost effective preventive measure in most industries. Our study data are undergoing further analysis, and will be pooled with data from five other studies in a future study that will allow more precise exposure response measures meant to provide specific guidance to workplace safety professionals on levels of exposure related to increased risks of CTS.

Section 1

Significant Key Findings

Key Findings for Specific Aim 1: *Compare the cumulative incidence of CTS in workers with and without baseline abnormalities of median nerve conduction, in order to test the predictive validity of pre-placement nerve conduction studies.*

Analyses from 18 month follow-up to date showed that of 86 (12%) of subjects with abnormal baseline nerve conduction studies (NCS), 21% reported new symptoms of CTS at 18 months, and 5 (6%) reported a new clinical diagnosis of CTS. Of subjects with normal baseline NCS, 4% had new symptoms and 5 (0.8%) had a new diagnosis of CTS. While abnormal baseline NCS predicted higher risk for the development of CTS symptoms or diagnosis, the majority of workers with abnormal NCS did not develop CTS or hand symptoms. Our data to date do not support the common practice of denying employment to those with abnormal NCS. Further analyses will be conducted on the longer-term follow up data. Study data from this aim were used to inform the cost analyses in Aim 3.

Key Findings for Specific Aim 2: *Measure the interaction between baseline nerve conduction abnormalities and physical job demands (repetitive and forceful movements) in conferring increased risk of CTS.*

We have found that the incidence of CTS is highest among the worker group (construction workers) that has both the highest prevalence of baseline nerve conduction abnormalities and the highest physical job demands. Analyses to assess the independence of these risks and their interaction at the level of the individual worker are ongoing.

Key Findings for Specific Aim 3: *Measure costs associated with workers' compensation claims for CTS, and estimate the costs per case of CTS detected by pre-placement, post-offer screening with nerve conduction studies.*

We conducted formal decision analysis of the cost-effectiveness of screening for CTS. Total costs for CTS from the perspective of the employer (screening costs plus costs for workers' compensation associated with CTS) were higher when screening was used. Under the no screening strategy, the costs of CTS over five years were $480 per new position hired (accounting for new hiring to make up for turnover), whereas the costs for the screening strategy were $776, a difference of $296 per employee position. Although the screening strategy did avoid some cases of CTS for the employer, the costs of screening more than offset the avoided costs of work-related CTS. In addition, most workers who were not hired because of abnormal nerve conduction would not develop CTS. Our sensitivity analyses show that a strategy of no screening will dominate so long as the annual turnover rate is more than 12% and the cost of the test is more than $45. In one-way sensitivity analyses, we also found that no-screening would dominate as long as the cost of a case is less than $66,000. Sensitivity analysis showed that a strategy of screening was cost-effective from the perspective of the employer only when the cost of each case was high, the employee turnover low, and the prevalence of baseline nerve conduction abnormalities was high. In the majority of simulations, a strategy of no screening was preferred.

Key Findings for Specific Aim 4: *Prospectively determine risk factors for CTS in a study that measures baseline nerve conduction values, workplace physical exposures, psychosocial factors, demographic and anthropometric variables, and history of concurrent medical conditions.*

We found that past work-related physical exposures were significantly associated with the prevalence of median nerve abnormalities, even after controlling for a number of demographic and medical covariates. At baseline, we studied exposures in past jobs using both self-reported physical exposures and exposures using an innovative job exposure matrix based on job titles and national data derived from O*NET. Age, body mass index, and a history of diabetes were all predictors of abnormal median nerve function. When controlled for both work and non-work related factors, a number of self-reported physical exposures in prior jobs were associated with abnormal nerve function, including the average daily duration of lifting, using vibrating hand tools, and working on an assembly line. Forearm twisting, wrist bending, and using forceful hand grip were significant in models adjusting for non-work factors, but due to covariance between work exposures, were not significant when all other work exposures were included. Job exposure matrix data based on job title determined exposures (and thus not subject to individual subjects' reporting bias) found significant associations with median nerve abnormalities and work requirements for force and repetition in multivariable models.

Translation of Findings

The significant findings of our study can be used to prevent diseases and injuries in several important ways.

Post-offer, pre-placement screening (pre-employment screening): Observations from our prospective cohort and from our decision analytic model suggest that for most employers such screening is not appropriate. Workplace screening policies are widespread, though they have rarely been subject to formal analysis. A strategy of pre-employment screening for CTS has low yield, yet results in social consequences as many workers must be denied employment to prevent each case of CTS in a given workforce. Our analyses suggest that this widespread practice is not useful as a preventive measure for CTS. Resources currently devoted to such screening could be directed to more productive activities.

Physical workplace exposures: Our study adds to the growing body of evidence that physical workplace exposures requiring repeated forceful grip confer higher risks for CTS even after adjustment for all relevant personal characteristics of workers. Efforts to prevent the common and costly condition of CTS should focus on ways to reduce these exposures.

Methods: Our study has published on several methodological aspects of research into UE MSD that are useful to other researchers and to safety professionals doing surveillance of disease or estimation of physical exposures. We have reported on the utility and the validity of simple methods for measuring nerve conduction in field research, for defining CTS, and for measuring workplace physical exposures.

Outcomes/Impact

Potential impacts of study findings relate to its contributions to methodology of research in CTS, its findings regarding the effects of physical workplace exposures and the development of CTS, and its findings that pre-employment screening for CTS is unlikely to be a cost-effective strategy for preventing this common and costly condition.

Section 2

Scientific Report

BACKGROUND

Carpal tunnel syndrome (CTS) is the most common upper extremity peripheral neuropathy, and carpal tunnel release surgery is the most commonly performed surgery of the hand, with approximately 200,000 procedures done annually in the United States (Levine et al. 1993). Estimated direct medical costs for CTS exceed one billion dollars annually (Levine et al. 1993). National data from the Bureau of Labor Statistics shows that among all major disabling workplace injuries and illnesses, median days away from work were highest for cases of CTS (BLS 2001).

Estimates of the frequency of CTS in both general populations and working populations vary widely, depending on the source of the information and the case definition. In the National Health Interview Study, 0.5% of working age adults reported that they had received the diagnosis of CTS from a medical provider (Tanaka et al. 1994). Using a case definition of physician diagnosis based on review of medical records, the incidence of CTS was found to be 6 cases per 1000 person years among Wisconsin residents aged 18-64 (Nordstrom et al. 1998a). In a surveillance study of computer users, 10.5% were found to meet clinical criteria for CTS, and 3.5% had CTS confirmed by nerve conduction studies (Stevens et al. 2001). A recent prospective study of office workers found an annual incidence of 0.9% (Gerr et al. 2002). A recent study in Italy used reports from electrophysiology laboratories to estimate a standardized incidence of CTS in a general population, which was 276 per 100,000 person-years in this study (Mondelli et al. 2002). In the largest general population study to date, a stratified sample of 3000 adults in Sweden found a CTS prevalence of 2.7% using a strict case definition which required symptoms, abnormal electrophysiological studies, and clinical diagnosis by a hand surgeon (Atroshi et al. 1999). Notably, blue collar workers had a higher prevalence of CTS (3.5%) than did white collar workers; a higher prevalence of CTS (5.4%) was also seen among workers who reported more than one hour per day of forceful use of the hands and among workers who reported the use of hand held power tools (5.5%). Other studies have found higher incidence and prevalence of CTS (up to 15%) among worker groups characterized by high-force, high-repetition work with the hands or use of vibrating hand tools (Masear et al. 1986).

The variability in estimates of CTS incidence and prevalence is due, in part, to variations in case definition. A consensus has emerged over recent years that CTS is a syndrome characterized by abnormal conduction at the median nerve AND characteristic symptoms. Case definitions based on symptoms alone or on nerve conduction studies alone have high rates of false positives, while definitions relying on medical claims or treatment data may seriously underestimate the true occurrence of disease due to untreated or unreported cases (Rempel et al. 1998; Atroshi et al. 1999).

Preventive strategies for CTS have been the focus of considerable scientific and political debate. A large and credible body of scientific evidence links work exposures to CTS, and suggests that a large proportion of CTS occurring among workers in high-risk industries is potentially preventable (NAS 2001). A growing and credible body of work suggests that workplace interventions aimed at reducing physical exposures can reduce the frequency of musculoskeletal disorders among workers (NAS 2001). However, this conclusion is not universally accepted, and a number of prominent physicians and academics believe that workplace ergonomic interventions are unproven and likely to be ineffective at reducing workplace musculoskeletal disorders (Hadler 1990, 1997, Vender et al. 1995, Szabo 2001). Given this controversy, alternative means to preventing work-related CTS have been implemented and advocated, including the use of screening tests prior to employment, with employment conditional on results of the testing. Instead of reducing the exposures incurred in high-risk jobs, this strategy aims to keep workers at high baseline risk for CTS from entering jobs that may place them at further risk for the development of CTS.

The role of pre-placement, post-offer screening for median neuropathy remains controversial. Previous studies have indicated that surveillance programs that rely only on symptoms and physical examination are likely to result in frequent misclassification of disease (Franzblau et al. 1994a, Rempel et al. 1998). Case definitions of CTS based on measures of nerve conduction are recommended by most researchers in the field as offering better diagnostic validity than those which lack this measure (Rempel et al. 1998, DeKrom et al. 1990b, Gerr and Letz 1998). Although they have been used in research settings, the cost, discomfort, and inconvenience of traditional nerve conduction studies has deterred their routine use in most screening and surveillance settings. The advent of easy to use, portable nerve conduction devices has made it easier to obtain nerve conduction data, but many questions remain about how these data can best be used.

Portable nerve conduction devices are now being introduced widely into occupational health practices, where they are being used for point-of-care diagnosis of median neuropathy in symptomatic workers. With increasing frequency, portable nerve conduction devices are also being used in pre-placement, post-offer medical evaluations. Proponents of testing believe that it identifies workers at higher risk of developing CTS, so that these workers will not be placed in jobs that further increase their risks of developing this disorder. Available studies indicate that asymptomatic workers with abnormal nerve conduction studies are at a higher risk of developing median neuropathy than asymptomatic workers whose nerve conduction studies are normal (Nathan et al. 1998, Werner et al. 2001). However, the magnitude of the increased risk conferred by nerve conduction abnormalities, the cost benefit of doing such screening, and the effectiveness of different placement strategies in preventing carpal tunnel syndrome all remain to be defined.

Despite a lack of clear scientific evidence that pre-placement, post-offer screening with nerve conduction studies is sufficiently predictive of future carpal tunnel syndrome, this practice is becoming increasingly common (CTD News 1995, Pruitt 1995). One factor limiting employers' use of screening in the past has been concerns over restrictions on pre-employment testing of workers defined by the Americans with Disabilities Act (ADA). This act forbids medical screening prior to an offer of employment, and mandates that post-offer employment testing can be done only for the purposes of worker placement or accommodation. An employee with a disability covered under the Act can be found unfit for a given job only if placement in that job would place the worker or others at a "high probability of substantial harm" (Hainer 1994). The practice of pre-placement, post-offer testing for median neuropathy is likely to become more common following recent court decisions that have favored employers' use of the practice over individuals claiming discrimination under the ADA.

Four court decisions taken in the past two years are likely to speed the diffusion of portable nerve conduction testing into the pre-placement medical examination. Among these court decisions is a case brought by 19 job applicants for manufacturing jobs who were not hired for production line work because of abnormal nerve conduction ascertained with a portable nerve conduction device. The 8th U.S. Circuit Court of Appeals ruled that the employer did not violate the Americans with Disabilities Act (ADA) when these job applicants were excluded from production jobs based on test results indicating that they were at increased risk for developing CTS in that job (EEOC vs. Woodbridge Corporation, 8th Circuit No. 01-L045, August 24th, 2001). In another case, the 7th Circuit Court of Appeals held that the Equal Employment Opportunity Commission could not prove that individuals tested for susceptibility for CTS were discriminated against under the ADA by a policy that rejected job applicants who had prolonged median nerve conduction studies (EEOC vs. Rockwell International Corporation, 7th Circuit Nos. 00-1897 & 00-2034, March 8, 2001). In 2002, the Supreme Court ruled that employers are not obligated to make job accommodations under the ADA for workers with CTS unless they are substantially disabled in essential life activities outside of work duties (Toyota Motor Manufacturing, Kentucky, Inc. v. Williams, certiorari to the United States Court of Appeals for the Sixth Circuit No. 001089). Also in 2002, the Supreme Court broadened the ability of employers to use screening laboratory tests to exclude workers from employment (Chevron U.S.A. Inc. v. Echazabal, 122 Supreme Court 2045).

There are no published estimates of the number of employers already making hiring decisions based on pre-placement screening for CTS. The topic of pre-placement screening is actively discussed in the occupational health community, including recent discussions on the e-mail list-serve operated by Duke University, which serves as a national sounding board for discussions in occupational health (occ-env-l@mc.duke.edu). The recent court decisions are likely to increase the use of pre-placement screening, as suggested by an article in the newsletter of the Society for Human Resource Management, "OK to Test, Reject Applicants Prone to Carpal Tunnel" (Greco-Danaher 2001).

The controversy over screening for CTS is part of a larger uncertainty over the independent contributions of work related and non-work related risk factors in the etiology of carpal tunnel syndrome. Despite an abundance of literature demonstrating that workplace physical exposures are a significant risk factor for CTS, there is still uncertainty over the relative contributions of work and non-work factors. Some authors have continued to assert that personal risk factors play a predominant role in the etiology of CTS, with little causation attributable to work exposures (Nathan et al. 1988, Hadler 1990, 1997, Vender et al. 1995, Szabo 2001). This controversy persists in part because few longitudinal studies have adequately measured both work exposures and individual risk factors such as body-mass index (BMI), other anthropometric data, medical history, and psychosocial factors.

The purpose of this proposal is to address scientific questions regarding the use of screening for CTS, and to evaluate risk factors for CTS in a large longitudinal study that combines quantitative data on job physical exposures with data on personal attributes that may increase the risk for development of CTS.

SPECIFIC AIMS

Specific Aim 1: Compare the cumulative incidence of CTS in workers with and without baseline abnormalities of median nerve conduction, in order to test the predictive validity of pre-placement nerve conduction studies. CTS will be defined through clinical examination with nerve conduction testing and ascertainment of symptoms, as well as through workers' compensation claims data and self-reports of diagnoses and treatment. Differing screening thresholds for defining normal and abnormal baseline nerve conduction will be tested for their predictive values.

Specific Aim 2: Measure the interaction between baseline nerve conduction abnormalities and physical job demands (repetitive and forceful movements) in conferring increased risk of CTS.

Specific Aim 3: Measure costs associated with workers' compensation claims for CTS, and estimate the costs per case of CTS detected by pre-placement, post-offer screening with nerve conduction studies.

Specific Aim 4: Prospectively determine risk factors for CTS in a study that measures baseline nerve conduction values, workplace physical exposures, psychosocial factors, demographic and anthropometric variables, and history of concurrent medical conditions.

RESULTS

In order to address the aims, we originally proposed a 3 year, prospective study of 1500 workers who were new or recent hires in a mixture of industries at increased risk for CTS. 450 of these workers would be followed in a subcohort with more intensive data collection. We have followed our original study plan with two significant changes. First, because of a large reduction (>20%) in our originally requested budget, we renegotiated with NIOSH a reduced cohort size to reflect the diminished budget. We recruited 1107 newly hired workers to our study, and performed the more intensive data collection on a subcohort of 483. Second, our recruitment took longer than originally expected - because we recruited newly hired workers to our cohort, our study recruitment was hindered by the major economic downturn in our region that started in 2004, because fewer employers were hiring new workers.

Accomplishments

Recruitment and Follow-up: Subject recruitment began in July of 2004 and was completed in October 2006. Our final enrollment included 1107 subjects with full baseline data. These subjects came from a variety of companies including three construction apprentice training programs (n=450), two hospitals (n=493), a biotech company (n=53), a utility company (n=7) and four manufacturing companies (n=104). Baseline data consisted of median and ulnar NCS, a focused physical examination with provocative maneuvers for CTS, and a questionnaire including work exposure history and a comprehensive assessment of personal risk factors for CTS. All enrolled workers were followed for 3 years through repeated questionnaires and collection of administrative data on workers compensation (WC) claims. In order to obtain more detailed data on job exposures and disease outcomes, a subset of the cohort (170 workers with abnormal baseline NCS and 313 matched comparison subjects) received expanded follow-up, consisting of job site visits for exposure assessment at six and 36 months following recruitment, and repeat NCS and physical examination at 36 months.

Follow-up rates were high, with over 86% still enrolled at the end of data collection. Of the 152 participants (13.7%) who had dropped from the study, 52% (n=79) were dropped by the PI because they could not be contacted for follow-up after numerous attempts; 40.8% (n=62) withdrew by choice stating that they did not have time or were no longer interested in participating, and 7.2% (n=11) were unable to participate (deceased, incarcerated, or on military deployment).

Questionnaires: We developed baseline and follow-up questionnaires incorporating questions and scales from multiple existing instruments. The baseline questionnaire covered the domains of work history, medical history, physical exposures at past jobs, and upper extremity musculoskeletal disease symptoms. The follow-up questionnaires included interval medical history and medical care, recent symptoms, disability related to upper extremity disorders, and physical and psychosocial exposures related to the current job. All follow-up questionnaires were adapted to a telephone interview format for subjects who were difficult to reach through mailings.

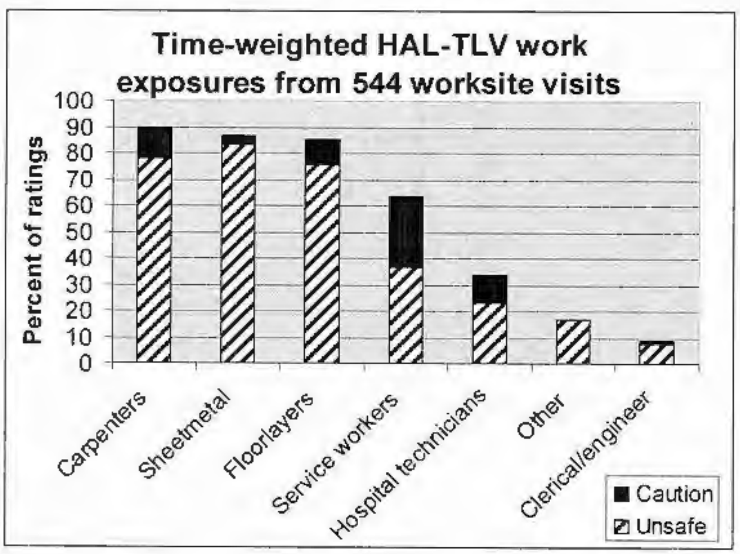
The follow-up rates for each survey were:

- <u>6-month</u>: Completed in October 2007 with 975 respondents (88% of cohort)
- <u>18-month</u>: Completed in October 2008 with 942 respondents (85%)
- <u>36-month</u>: Completed in September 2009 with 889 respondents (80%)

Physical Exam (PE) and Nerve Conduction Study (NCS) Protocol: We developed a short PE protocol, trained our field examiners in its use, and produced a training video to assist standardization of the exams. We also developed standardized procedures for performing the NCS with the NC-Stat automated testing device, and have cooperated with the University of California NIOSH consortium study to standardize our approaches (they use the same device in their study). We published a validation study of the NC-Stat device (Armstrong 2008) used in our study and the University of California study.

Case Definitions: We developed interpretation rules for the NCS and for the hand diagrams contained in the questionnaires to classify workers with respect to different CTS outcomes. Coding of hand diagrams for CTS likelihood was performed independently by 3 raters (2 physicians and one hand therapist) with differences resolved by consensus. We worked actively with other researchers to develop consensus case definitions that will allow data pooling within the NIOSH consortium described below.

Exposure Assessment: Work exposures were obtained using three data collection methods: self-report, job-title based estimates, and worksite observations. The self-reported items of work exposures on each questionnaire included upper extremity work activities of force, repetition, postures, and vibration, and are derived from existing validated scales (Nordstrom 1998, Silverstein 1997, Latko 1997). Job-title based estimates utilized the Occupational Information Network (O*NET http://www.onetcenter.org/), a public database containing quantitative exposure information on multiple work component variables for over 900 occupations (Consortium ON 2007). Worksite observations consisted of a brief interview with the subject and supervisor, work observations, and videotaped samples of key work tasks. Videotapes and other job site information were coded by at least two trained evaluators (experienced ergonomist, or physician or hand therapist with ergonomics training), with differences resolved by consensus. Inter-rater reliability values between evaluators produced ICC scores from 0.71 to 0.86 for the key exposures. Each job was divided into tasks and rated for peak hand force, mean hand force, hand activity (repetition), and wrist and shoulder postures using the peak hand force and hand activity level. The HAL-TLV ratio was calculated as described by the American Conference of Governmental Industrial Hygienists (ACGIH) Hand Activity Level Threshold Limit Value (HAL-TLV) (2001).



We performed 665 exposure assessments in the field, including 201 repeat assessments at the 36-month time point. The figure shows the summary HAL-TLV data for 7 job categories from our study data. The time weighted average HAL-TLV was categorized into "safe," "caution," and "unsafe" exposures as described in the TLV. Our cohort had wide heterogeneity of exposures; workers in construction trades had the highest exposures with nearly all workers exposed above an acceptable limit.

Repeat nerve conduction testing: We invited select cases and controls to complete the repeat NCS and PE protocol. Of the 589 subjects contacted, 486 completed the repeat testing protocol. The testing protocol was identical to the one used at baseline. Subjects were contacted either at home or through their employer and invited to participate in the repeat testing.

NIOSH Consortium Activities: We have participated actively in the NIOSH coordinated Work-related Musculoskeletal Disorder Consortium (MSDC), a group of 7 prospective cohort studies aimed at quantifying the risks for upper limb MSDs at varying levels of exposure to physical job stressors. By standardizing methods and pooling data, the Consortium seeks to provide a quantitative understanding of the exposure-response relationships between ergonomic risk factors at the workplace and the risk for developing hand, wrist, and elbow MSDs across various occupations and industries. Participation in this consortium has provided the opportunity for sharing information on data collection methods and analytical procedures; all of our study instruments have been shared with the consortium. Our study team has helped to lead efforts to develop common research case definitions of CTS, and to arrive at common exposure definitions so that data pooling efforts can proceed in 2009. Dr. Evanoff organized a multi-presenter symposium on the "NIOSH Consortium Studies of Musculoskeletal Disorders" at the 2007 PREMUS conference; we are planning a similar session with other consortium members at the International Ergonomic Association (IEA) conference in 2009. The consortium members have agreed on a common research case definition for CTS and other MSDs and have agreed on some common exposure metrics including the HAL-TLV. A proposal for analysis of pooled data will be submitted to NIOSH in early 2009.

Significant Findings to Date: We have published or presented new and useful findings in several important areas, including risk factors for CTS and other symptomatic or functional outcomes, assessment of methods for case definition and exposure assessment, and the effectiveness of POPP screening. The richness of the data collected from our prospective cohort has allowed us to study a variety of outcomes and perform methods assessments that were not major aims of the original grant proposal.

Risk factors for CTS and other outcomes: Findings from analysis of our baseline data (Armstrong 2008) found 1.6% of workers meeting our case definition of CTS (similar to other general population studies). CTS was highest among construction workers (3.0%) compared to other subjects (<1%). 11.8% of subjects met our strict definition of median nerve conduction abnormalities, which were predicted by personal factors (BMI, age, wrist anthropometrics, and history of UE tendonitis or diabetes). After controlling for these personal factors, median nerve abnormalities were also predicted by both self-reported exposures and by exposure estimates derived from job titles using a national job task database (O*NET). Using our 6 month follow-up data, we identified personal and work-related predictors of upper extremity symptoms and related functional impairment, based on a composite definition that included changes in job duties, productivity, lost work time, or changes in functional status as measured by the Levine scale (Gardner 2008). Independent predictors for UE symptoms at 6-month follow-up were age, Caucasian race, female gender, baseline history of UE symptoms, and job tasks involving wrist bending or forceful gripping. Independent predictors for functional impairment were baseline history and severity of UE symptoms, wrist bending, and social support. Analysis of the 18 month follow-up data found high rates of one year cumulative incidence of symptoms characteristic of CTS (5.6%), hand/wrist discomfort (13.9%), and functional impairment (14.3%) among those who completed both the 6 month and 18 month questionnaires. Workplace physical and psychosocial factors were independent predictors, as were personal factors including BMI (presented at NOIRS in 2008). We also studied predictors of job turnover and income loss in this population (presented at APHA in 2008).

We also evaluated our highest risk group, construction workers, to examine the prevalence of CTS and associated physical risk factors compared to other work types. Using only those workers form our subset with observed exposures and who had been in the same job for 3 years, we used multivariate logistic regression analysis to evaluate job category (construction workers versus other industries) to cases defined as abnormal median neuropathy or as CTS (symptoms plus median neuropathy). Differences in self-reported and observed physical work exposures between work groups were evaluated using t-tests and ANOVA. Of 411 subjects, there were few cases of CTS (n=21), but high frequency of median neuropathy (n=117; 18.1%) at 3 years. Job distribution was 256 (62%) construction workers (carpenters, floor layers, or sheet metal workers) and 155 (38%) workers from other industries (clerical, computer workers, food service, housekeeping, laboratory, and health technicians). Construction workers were younger (26 versus 38 years, $p<0.01$), leaner (BMI: 26.7 versus 30.3, $p<0.01$), and male (100% versus 32%, $p<0.01$) compared to the other workers. Construction workers were two times more likely to have median neuropathy than other workers (OR= 2.1, 95% CI: 1.2, 3.8) after controlling for age and BMI. Construction physical exposures had higher level of peak hand force (5.6 versus 3.0, $p<0.01$), hand activity level (4.1 versus 3.0, $p<0.01$) on 0 to 10 (highest level) rating scales, and ACGIH HAL-TLV (0.96 versus 0.44, $p<0.01$). All self-reported exposures had higher mean exposures for the construction group. These data show that construction workers have significantly higher levels of work exposures and greater frequency of abnormal median neuropathy compared to workers in several other industries. Numerous barriers exist to the implementation of recognized methods to reduce physical exposures in construction in the United States; continued efforts are required to reduce the burden of injury in this high-risk industry.

Case definition: In order to provide more information on the comparability of NCS performed with the automated nerve testing device used in our study versus traditional methods, we performed both tests on 33 subjects who were referred for standard NCS. Sensitivity with respect to the traditional results ranged from 93.8% (sensory MUD) to 100% (median DML and DSL) and specificity ranged from 84.6% (motor MUD) to 94.1% (sensory MUD) (Armstrong 2008). We have also evaluated the reliability of hand diagrams for the epidemiologic case definition of CTS, finding excellent agreement (weighted kappas 0.83 – 0.88) between our three independent raters (Dale 2008). Importantly, disagreement between raters was not affected by subjects' work or personal factors, indicating that these outcome ratings are likely to be unbiased by potential risk factors. We are currently examining the performance of physical examination, NCS, and symptoms for the research case definition of CTS.

Exposure assessment: We have completed two manuscripts that assessed inter-method comparisons of physical exposure estimates. We compared the agreement between our self-reported and observed exposure estimates in 341 subjects and found substantial agreement using weighted kappa values for lifting (0.67) and holding vibrating tools (0.61), moderate for forceful grip (0.58), and fair to poor for other exposures. We also used job-titles to obtain physical work exposures for 972 workers in our cohort and compared the estimates to self-reported and to observed exposures. These results showed moderate to good levels of agreement for some items indicating job-title based physical exposures may be a useful surrogate measure in the absence of individual level data. We anticipate that these manuscripts will be published in the next year.

Other methods assessments: We described our efforts to recruit employers to our study, and examined employers' reasons for declining participation, which included lack of interest, liability concerns, time constraints, and lack of perceived benefit to the employer (Johnson 2008). We hope that by understanding factors affecting employers' decisions, researchers can better secure the participation necessary to conduct workplace studies. We have also presented on the challenges of performing exposures measurements in construction work (presented at APHA in 2007), and the challenges of exposure measurement and research case definitions for CTS (presented at PREMUS in 2007).

Effectiveness of POPP screening: We have recently presented an analysis of 932 workers with 18 month follow-up data and compared results between those for normal baseline NCS versus abnormal baseline NCS. At 18 months, new symptoms of CTS were reported more commonly in the group with abnormal baseline NCS (12.8% vs. 4.2%), as were new clinical diagnoses of CTS (6.0% vs. 0.7%). CTS symptoms or diagnosis occurred in 21% of those with baseline abnormalities. However, 62% of new symptoms or diagnoses occurred in those with normal baseline NCS, calling into question the value of a POPP screening program (Armstrong 2008c).

We also conducted a formal decision analysis modeling the cost effectiveness of nerve conduction studies in pre-employment screening for CTS (Evanoff 2009). Because the yield and cost-effectiveness of screening strategies for occupational diseases are rarely subjected to formal analysis, we developed an analytic model to estimate the cost-effectiveness of pre-employment nerve conduction testing as a screening tool for CTS in the workplace. We used a Markov decision analysis model to compare the costs associated with a strategy of screening all prospective employees for CTS and not hiring those with abnormal nerve conduction (as is done by some large employers in the USA) versus a strategy of no screening for CTS. The variables included in our model were employee turnover rate, the incidence of CTS, the prevalence of median nerve conduction abnormalities, the relative risk of developing CTS conferred by abnormal nerve conduction, the costs of screening, and the costs per case of CTS. Accounting for variability in the model's parameters, we estimated the number of screenings needed to prevent one case of CTS, the number of workers who would be rejected for employment based on screening, and the associated costs of screening versus not screening. In our baseline model, total costs for CTS from the perspective of the employer (screening costs plus costs for workers' compensation associated with CTS) were higher when screening was used. Under the no screening strategy, the costs of CTS over five years were $480 per new position hired (accounting for new hiring to make up for turnover), whereas the costs for the screening strategy were $776, a difference of $296 per employee position. Although the screening strategy did avoid some cases of CTS for the employer, the costs of screening more than offset the avoided costs of work-related CTS. In addition, most workers who were not hired because of abnormal nerve conduction would not develop CTS.

Our sensitivity analyses show that a strategy of no screening will dominate so long as the annual turnover rate is more than 12% and the cost of the test is more than $45. In one-way sensitivity analyses, we also found that no-screening would dominate as long as the cost of a case is less than $66,000. Sensitivity analysis showed that a strategy of screening was cost-effective from the perspective of the employer only when the cost of each case was high, the employee turnover low, and the prevalence of baseline nerve conduction abnormalities was high. In the majority of simulations, a strategy of no screening was preferred.

A strategy of pre-employment screening for CTS should be carefully evaluated for yield and social consequences before being implemented; both observations of our prospective cohort, and our decision analytic model suggest that for most employers such screening is not appropriate. Workplace screening policies are widespread, though they have rarely been subject to formal analysis. Our analyses suggest that this widespread practice is not useful.

CONCLUSIONS

To date, our study has recruited a large prospective cohort of 1107 workers in a variety of industries, obtained rich baseline data including nerve conduction studies and physical examination, and obtained serial follow-up data on a large proportion of these workers (80% follow-up at 3 years). Our study is unique in that it is very large, it studies a wide variety of industries (not just manufacturing as many CTS studies do), and it is an inception cohort, and thus less subject to biases resulting from healthy worker survivor effect that may limit the interpretation of other prospective cohort studies of CTS. Although recruitment was slowed due to large regional decreases in hiring of new workers during the first three years of our study, we successfully recruited and followed a large cohort of workers. To date, we have published five peer-reviewed manuscripts from our study, which have addressed scientific aims of the study and have enriched the methodological literature around studying this common and costly health condition. Analyses of study data are ongoing, and we anticipate that a large number of findings will result from our study in the next several years; some of these findings have been presented at scientific meetings. We have applied for funding for an extension of our study to provide follow-up of all workers with nerve conduction studies at 3 years and to follow participants for an additional 3-4 years, lengthening the period of follow-up. We are also working with other members of the NIOSH UE MSD consortium on a proposal to pool study data from six studies, and to analyze the resulting large dataset in order to have more statistical power to ascertain dose-response relationships between work exposures and CTS.

Inclusion Enrollment Report

Study Title: Post-offer screening and risk factors for CTS

Total Enrollment: 1107 **Protocol Number:** 04-0221

Grant Number: 5 R01 OH008017

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race

	Sex/Gender			
Ethnic Category	**Females**	**Males**	**Unknown or Not Reported**	**Total**
Hispanic or Latino	6	6		12 **
Not Hispanic or Latino	379	713		1,092
Unknown (individuals not reporting ethnicity)	1	2		3
Ethnic Category: Total of All Subjects*	386	721		1,107 *
Racial Categories				
American Indian/Alaska Native	1	1		2
Asian	14	10		24
Native Hawaiian or Other Pacific Islander	0	0		0
Black or African American	211	169		380
White	152	526		678
More Than One Race	1	0		1
Unknown or Not Reported	7	15		22
Racial Categories: Total of All Subjects*	386	721		1,107 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)

Racial Categories	**Females**	**Males**	**Unknown or Not Reported**	**Total**
American Indian or Alaska Native				
Asian		1		1
Native Hawaiian or Other Pacific Islander				
Black or African American	2			2
White	1			1
More Than One Race				
Unknown or Not Reported	3	5		8
Racial Categories: Total of Hispanics or Latinos**	6	6		12 **

* These totals must agree.
** These totals must agree.

Publications

Johnson AM, Dale AM, Strickland JR, Venditti P, Evanoff BA: [2008]. Employers' concerns regarding research participation. International Journal of Occupational and Environmental Health. 14:11-7. PMID: 18320727

- *This article does not directly relate to any specific aim, but describes the challenges of doing large scale recruitment for this study, and thus provides useful information for other occupational health and safety researchers who rely on employer participation.*

Armstrong TN, Dale AM, Al-Lozi MT, Franzblau A, Evanoff BA: [2008]. Median and ulnar nerve conduction studies at the wrist: criterion validity of the NC-stat automated device. Journal of Occupational and Environmental Medicine. 50:758-64. PMID: 18617831.

- *This article provides information about the validity of the NC-Stat device, one of the most commonly used screening devices used by employers performing CTS pre-placement examinations, and thus relates directly to Aims 1 and 3; it also addresses an issue raised by study reviewers that is relevant to Aims 1, 2, and 4.*

Dale AM, Strickland J, Symanzik J, Franzblau A, Evanoff BA: [2008]. Reliability of hand diagrams for the epidemiologic case definition of carpal tunnel syndrome. Journal of Occupational Rehabilitation. 18:223-48. PMID: 18521726.

- *This article provides information about the reliability of utilizing hand diagrams to determine carpal tunnel syndrome, and relates to the methodology of Aims 1, 2, and 4.*

Gardner BT, Dale AM, VanDillen L, Franzblau A, Evanoff BA: [2008]. Predictors of upper extremity symptoms and functional impairment among workers employed for 6 months in a new job. American Journal of Industrial Medicine. 51(12):932-40. PMID: 18651568.

- *This article relates to Specific Aim 4 by prospectively describing risk factors for upper extremity disorders including CTS.*

Armstrong T, Dale AM, Franzblau A, Evanoff BA: [2008]. Risk factors for Carpal Tunnel Syndrome and median neuropathy in a working population. Journal of Occupational and Environmental Medicine. 50:1355-64. PMID: 19092490.

- *This article relates to Specific Aim 1 by showing baseline rates of neuropathy, and to Aim 4 by showing the effects of past job exposures, demographic factors, and anthropometric variables on the risk of CTS.*

Peer reviewed abstracts and presentations

2005

"Feasibility of a Job Exposure Matrix for Exposure Assessment in WMSD Research." EPICOH, Bergen, Norway, Sweden, 9/05

2006

"Employers Concerns Regarding Research Participation." APHA 134th Annual Meeting and Exposition, Boston, Massachusetts, 11/06

"Comparison of Measured Hand Force to Estimated Hand Force for Fastener Installations." Proceedings of the International Ergonomics Association, Maastricht, Netherlands, 2006

2007

"Assessment of Risk Factors Associated with Upper Extremity Disorders in a Working Population." American Occupational Therapy Association National Meeting 4/07

"Barriers to Conducting Field Research in Residential Carpentry." APHA 135th Annual Meeting and Expo, Washington, DC, 11/07

"Barriers to Doing Field Research in Residential Carpentry." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Median and Ulnar Nerve Conduction Studies at the Wrist: Comparison of Automated and Traditional Methods." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Nerve Conduction Device Comparison." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Predictors of Upper Extremity Symptoms and Functional Impairment Among Workers Employed for 6 Months in a New Job." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Reliability of Hand Diagrams for Epidemiologic Case Definition of Carpal Tunnel Syndrome." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Risk Factors for Carpal Tunnel Syndrome in a Population of Newly Hired Workers: A Cross-Sectional Analysis." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Risk Factors of Upper Extremity Symptoms and Functional Impairment in a Working Population." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Validity of Self-reported Physical Work Activities and Exposure Misclassification." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

"Validity of Self-Reported Physical Work Activities and Predictors of Over-and Under-Reporting." PREMUS 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorders, Boston, Massachusetts, 8/07

2008

"Employment Screening for Carpal Tunnel Syndrome Using Nerve Conduction Studies is Not Supported by Current Evidence." APHA 136th Annual Meeting and Expo, San Diego, California, 10/08

"Physical Exam Measures Have a Low Yield in Employment Screening for Carpal Tunnel Syndrome." APHA 136th Annual Meeting and Expo, San Diego, California, 10/08

"Predictors of CTS at 18 months." National Occupational Injury Research Symposium, Pittsburgh, Pennsylvania, 10/08

"Work-Related Physical and Psychosocial Exposures are Risk Factors for Incident Symptoms and Functional Impairment of the Hands and Wrists." National Occupational Injury Research Symposium, Pittsburgh, Pennsylvania, 10/08

"Estimation of Physical Exposures Experienced During Highly Variable Work Tasks in Residential Construction" NORA Symposium 2008, Denver, Colorado, 7/08

"Targeting High Risk Tasks in Residential Construction." NORA Symposium, 2008

2009

"Cost Effectiveness of Screening for Carpal Tunnel Syndrome." Economic Dimension of Occupational Safety and Health Workshop, Amsterdam, The Netherlands, 9/09

"Comparison of Exposure Methods in Home Building Carpenters." Proceedings of the International Ergonomics Association, 2009

"The Predictors of Carpal Tunnel Syndrome Study in Saint Louis." Proceedings of the International Ergonomics Association, 2009

"Reliability of observed physical exposures during highly variable work tasks in residential construction." Proceedings of the International Ergonomics Association, 2009

"Risk Factors for Incident Carpal Tunnel Syndrome: Results of a Prospective Cohort Study of Newly-Hired Workers." Accepted for presentation at PREMUS and WDPI: Seventh International conference on Prevention of Work related Musculoskeletal Disorders. Angers, France, 9/10

"Variability of Observed Upper Extremity Physical Exposures Among Different Job Types." Accepted for presentation PREMUS and WDPI: Seventh International conference on Prevention of Work related Musculoskeletal Disorders. Angers, France, 9/10

"What Are the Strongest Predictors of the Medical Prognosis for CTS? Results from a US Population Based Study." Accepted for presentation PREMUS and WDPI: Seventh International conference on Prevention of Work related Musculoskeletal Disorders. Angers, France, 9/10

"Work Exposures and Carpal Tunnel Syndrome Among Construction Workers." Accepted for presentation PREMUS and WDPI: Seventh International conference on Prevention of Work related Musculoskeletal Disorders. Angers, France, 9/10

Inclusion of Gender and Minorities

There was no exclusion from this study on the basis of gender; approximately 35% of the cohort was female. Women of child bearing age were not excluded; however excluded pregnant women as the physiological changes of pregnancy may alter nerve conduction values. Women who became pregnant after enrollment were retained in the study and follow-up nerve conduction studies were delayed to avoid testing during pregnancy.

There was no exclusion from this study on the basis of race or ethnicity. The racial and ethnic distribution of the cohort was 61.3% Caucasian, 34.3% African American, and 4.4% other minority groups.

Inclusion of Children

Only workers who were 18 years of age or older were eligible for study participation. Workers under the age of 21 (but at least 18) were included.

Materials available for other investigators

Our research data are being made available to the NIOSH UE MSD consortium studies as part of a pooled dataset of baseline and follow-up personal factors, symptom and nerve conduction study outcomes, and physical exposures. These data will be made available to other investigators via the consortium.

Descriptions of our data collection protocols have been described publicly in several venues, have been shared among consortium investigators, and will be freely provided on request to other investigators.

Form Approved Through 08/31/2015
OMB No. 0925-0002

Department of Health and Human Services **Final Invention Statement and Certification** *(For Grant or Award)*	DHHS Grant or Award No. 5R01OH008017-05

A. We hereby certify that, to the best of our knowledge and belief, all inventions are listed below which were conceived and/or first actually reduced to practice during the course of work under the above-referenced DHHS grant or award for the period

06/01/2004 through 05/31/2009 .

original effective date — *date of termination*

B. Inventions (Note: If no inventions have been made under the grant or award, insert the word *"NONE"* under Title below.)

NAME OF INVENTOR	TITLE OF INVENTION	DATE REPORTED TO DHHS
	None	
(Use continuation sheet if necessary)		

C. Signature — This block *must* be signed by an official authorized to sign on behalf of the institution.

Title	Name and Mailing Address of Institution
Director of Grants	Washington University Sponsored Research Services Campus Box 8018 660 South Euclid Avenue St. Louis, Missouri 63110-1010
Typed Name Ms. Teri Medley	
Signature: [signature] Acting for Teri Medley — Date: 1-30-13	

[signature] 1/29/13

* Project is ongoing through 5/31/2014 per renewal NOA issued 8/17/2009.

HHS 568 (Rev. 08/12)

CDC Procurement & Grants Office - Branch V
Equipment Inventory Listing

Report Date:	2/18/13	Grant Number:	R01 OH008017
Project Title:	Post-offer screening and risk factors for CTS	Project Period:	6/1/2004 - 5/31/2009
Grantee Name:	Bradley Evanoff	Project Officer:	Maryann Monroe
Grants Management Officer:	Teri Medley	Grants Specialist:	Richard Fair

Description of Item: i.e. pH Meter	Mfr.[1] i.e. Fischer	Serial Number	Quantity	Condition[2]	Location[3]	Purchase Cost	Date Received [mm/dd/yyyy]
none							

[1]Mfr. (Manufacturer)
[2]Condition: (Excellent) (Good) (Fair) (Poor) (Inoperable)
[3]Location: complete physical address

For Government Use Only, not to be completed by the Grantee
Property Administrator & PO Disposition Recommendation and Instructions:

Description of Item	Disposition[1]	Address[2]
[Copy from above]	____Transfer Title	Attn: [Project Officer]
	____Retain and Compensate Awarding Agency	CDC / NIOSH
	____Return to Program Office	1600 Clifton Road, NE MS E-74
	____Other (explain)	Atlanta, GA 30329-4018
[Copy from above]	____Transfer Title	
	____Retain and Compensate Awarding Agency	
	____Return to Program Office	
	____Other (explain)	

[1]Check the appropriate disposition
[2]CDC Warehouse is the central receiving point for delivery of all non-hazardous and non-perishable supplies and equipment, CDC - AM–2004-03, update 2010