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Personal and workplace factors and median nerve function in a pooled study of 2396 US workers

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Abstract

Objective—Evaluate associations between personal and workplace factors and median nerve conduction latency at the wrist.

Methods—Baseline data on workplace psychosocial and physical exposures were pooled from five prospective studies of production and service workers (N=2396). During the follow-up period, electrophysiologic measures of median nerve function were collected at regular intervals.

Results—Significant adjusted associations were observed between age, BMI, gender, peak hand force, duration of forceful hand exertions, TLV for HAL, forceful repetition rate, wrist extension, and decision latitude on median nerve latencies.

Conclusions—Occupational and non-occupational factors have adverse effects on median nerve function. Measuring median nerve function eliminates possible reporting bias that may affect symptom-based carpal tunnel syndrome (CTS) case definitions. These results suggest that previously observed associations between CTS and occupational factors are not the result of such reporting bias.

Keywords

epidemiology; entrapment neuropathy; median neuropathy; risk factors; biomechanics; psychosocial; physical exposure

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The authors declare no conflicts of interest.

INTRODUCTION

Carpal tunnel syndrome is a common condition among workers with reported prevalence rates between 3 and 11% depending on the industry studied (DeKrom, 1992; Palmer et al, 2007, Silverstein 2010, Dale 2013). It is associated with considerable disability and risk of job loss (Faucett, 2000; Foley, 2007). There remains some controversy over specific workplace factors associated with carpal tunnel syndrome and their exposure-response associations due to imprecise exposure measures, differences in study outcomes, small sample sizes and lack of longitudinal studies (Palmer et al, 2007).

The physiologic hallmark of carpal tunnel syndrome is median nerve mononeuropathy at the wrist. Electrophysiologic evidence of median mononeuropathy is ascertained by measurement of median nerve conduction parameters, most commonly conduction latency and conduction velocity. Although the classic clinical definition of carpal tunnel syndrome requires both characteristic symptoms as well as electrophysiologic abnormality (Rempel et al, 1998), use of electrophysiologic measures alone has several advantages. First, unlike symptom reporting, electrophysiologic measures are free of any potential participant or investigator biases associated with knowledge of exposure circumstances. Second, while symptoms in the distribution of the median nerve may be due to a wide range of potential pathologies, isolated median mononeuropathy is highly specific for localized median nerve dysfunction consistent with carpal tunnel syndrome. Finally, unlike symptoms, electrophysiologic parameters can be analyzed as continuous variables, thereby improving statistical power.

In the current study, electrophysiologic measures of median nerve function were available for a large number of participants who were included in five NIOSH-funded studies examining associations between occupational risk factors and a wide range of upper extremity conditions and disorders, including carpal tunnel syndrome. In order to examine the purely physiologic effects of occupational exposures on median nerve function, we explored associations between electrophysiologic measures of median nerve conduction latency across the wrist and individual level exposures to occupational psychosocial and biomechanical risk factors while controlling for personal factors such as age, gender and obesity. Associations of personal and occupational factors to the classic clinical case definition for CTS, e.g., characteristic symptoms plus electrophysiologic abnormality, using this dataset, have been published elsewhere (Harris-Adamson et al, 2013; Harris-Adamson et al, in review).

METHODS

Participants

Six research groups conducted coordinated prospective studies of production and service workers at 54 companies in the US to evaluate personal and work-related risk factors for upper extremity disorders. We have previously described the details of study designs, inclusion criteria, and the process of pooling health outcome and exposure data (Dale et al, 2013; Kapellusch et al, 2013). This analysis only includes data from the four research groups that (i) measured median and ulnar nerve latencies at the wrist at regular intervals and (ii) measured job task level biomechanical exposures of the hand among participating workers (N=2868; sites A, B, C & E; Dale et al, 2013). Potential participants were ineligible if they had a prior carpal tunnel release surgery (n=36), had baseline (n=55) or incident (n=26) polyneuropathy (defined below), or worked less than one year on the job (N=309). There was varied representation of workers across standard industrial classification (SIC) divisions with nearly all coming from the agriculture (7%), manufacturing (81%) and service (12%) industries.

Data Collection

In all four studies, questionnaires were administered at enrollment (baseline) to collect information on work history, demographics, medical history and musculoskeletal symptoms. All studies collected electrophysiological measures across the wrist including median nerve sensory latency, median nerve motor latency, and ulnar nerve sensory latency. The methods used by each site have been previously described (Dale et al, 2013). Investigators responsible for collecting nerve latency measures were blinded to exposure status. Exposure was assessed on the individual level at baseline for all studies. For most subjects, symptom assessment, physical examinations, and EDS were repeated at regular follow-up intervals (Dale et al 2013; Kapellusch et al, 2013). If repeated electrophysiological measures were performed during the follow-up period, then the last measurement was used for the current analyses.

Personal Factors

Age, gender, BMI, race/ethnicity, education, smoking status, hand dominance, and co-morbid medical conditions such as rheumatoid arthritis, diabetes mellitus, and thyroid disease status were collected from all participants. General health was assessed on a 5-point scale from ‘poor’ to ‘excellent’.

Occupational Factors

Survey or interview questions regarding the psychosocial work environment were administered at study enrollment in three of the four studies. Items from the Job Content Questionnaire (Karasek 1998) were used to calculate psychological job demand and decision latitude scale scores. The psychological demand scale is based on 5 items (excessive work, conflicting demands, insufficient time to work, work fast, work hard). The decision latitude scale is based on skill discretion (e.g., learning new things, task variety, etc.) and decision authority (choice in how to perform work and making decision).

Biomechanical Workplace Exposures

All studies measured workplace exposures within the biomechanical domains of hand force, hand repetition, hand duty cycle, and wrist posture. Measurements were made at the level of the job task, using methods comparable to those used in previous studies (Silverstein et al, 1987; Chiang et al, 1993; Bernard, 1997; Fung et al, 2007; Maghsoudipour et al, 2008; Bonfiglioli et al, 2013). For most exposure domains, multiple variables were calculated to quantify specific exposure metrics (Kapellusch et al, 2013). For three study sites, analysts recorded the presence or absence of hand vibration by task.

The pooled data set included estimates of peak force – the highest force requirements of a task – using the Borg CR-10 rating scale, and estimated separately by workers and analysts. Temporal exertion patterns such as repetition and duty cycle were determined by detailed time studies of videotapes of subjects performing their tasks. The hand activities of the workers were analyzed on a frame-by-frame basis by trained analysts who were blinded to the health status of workers. Estimates of the repetitiveness of a task were quantified using the analyst HAL rating (verbal anchors), the total number of all exertions per minute based on video analysis, and the total number of forceful exertions per minute based on video analysis and task force data. Forceful exertions were those performed at greater than 45N of power grip, greater than 9N of pinch, or rated as >= 2 on the Borg CR-10 scale. Duty cycle was quantified from video analysis as percent time for all hand exertions and also the percent time for forceful hand exertions. Posture was quantified from video analysis as the percent time spent in >30° of wrist extension and the percent time spent in >30° of wrist flexion, as measured from a neutral (0°) wrist position. Finally, any (yes/no) exposure to hand/arm vibration through visible hand/arm vibration and/or use of vibratory hand-tools was recorded by task. A composite exposure score for each task was calculated using the combination of analyst HAL scale and analyst peak force according to the methods described for the ACGIH TLV for HAL (ACGIH 2014). Further details on exposure assessment methods are described in a prior publication (Kapellusch et al, 2013).

Job physical exposures were collected at baseline for each task (up to 8) that each worker performed. If workers performed multiple tasks for their job, then a job level exposure was calculated using time weighted averaging (TWA) where each task level exposure was weighted by the proportion of time the task was performed each week.

Outcomes

The primary outcome measures were the median peak sensory latency, median motor latency, and median-ulnar peak sensory latency difference (MUD) collected from the dominant hand of each participant. Subjects were excluded from the analysis if they had polyneuropathy defined as ulnar sensory peak latency ≥3.68 ms (corresponds to a conduction velocity of 44 m/s).

Statistical analysis

Regression coefficients were estimated using multiple linear regression with separate analyses conducted for each of the three outcome measures. TWA exposures were included in the regression models as continuous independent variables. Potential confounding by personal factors was assessed using both empirical observation and by directed acyclic graphs (DAGs) to posit structural relationships among the variables. DAGs are a method of modeling variables that considers the ordering of the variables in a potential causal pathway. Covariates not on the pathway from exposure to outcome and that were available for >=90% of the participants were initially included in each model as potential confounders. Those covariates that changed the effect estimate of the primary exposure variable by more than

10% on removal from the model were subsequently included in the final models to adjust for confounding. Because of prior research demonstrating important associations between age, gender and BMI and incident CTS, these factors were retained in every model regardless of strength of association in this sample (Harris-Adamson et al, 2013). Co-morbid medical conditions were not included in any models since all prevalent and incident polyneuropathy cases were excluded from the analysis.

To provide the least biased estimates of associations between exposure and outcome, models examining associations between each biomechanical exposure metric and each outcome metric were adjusted by study site and by one variable from each of the other biomechanical exposure domains (force, repetition, duty cycle and posture). Because each exposure domain had more than one candidate variable, the variable within each domain with the highest number of participants was selected to maximize statistical power. In addition to adjusted model R^2, a dimensionless metric of effect size analogous to *Cohen's d* was calculated or each exposure variable (Cohen, 1988). Specifically, the effect size metric was calculated as follows:

$$\text{Effect size}=(\text{interquartile range of exposure variable}^{*}\beta\,\text{exposure variable})/\text{SD dependent variable}$$

Essentially, the effect size metric is the magnitude of change in the dependent variable resulting from an interquartile range value of change in the exposure variable, reported in units of dependent variable standard deviation. The effect sizes for *Cohen's d* are small effect ≥ 0.2, medium effect ≥ 0.5, and large effects ≥ 0.8 (Cohen, 1988). All analyses were implemented with the Stata statistical package (Stata, College Station, TX).

RESULTS

Of the 2442 potential participants, those with unobtainable nerve latency measures (N=23) or no workplace exposure data (N=23) were eliminated from the current analyses. Demographic and occupational characteristics of the 2396 participating workers are provided in Table 1; demographic characteristics are similar to US workplace data (BLS, 2014). Approximately 11% of subjects reported a physician diagnosed medical condition (e.g, diabetes, rheumatoid arthritis, thyroid disorder, or pregnancy) and 10% reported a previously diagnosed distal upper extremity disorder. Most participants (72%) had worked for more than three years; the number of years worked was correlated with age ($R^2 = 0.46$, data not shown).

Summary measures of upper extremity biomechanical exposures, psychosocial measures, and nerve latency values are provided in Table 2. Some of the measures were collected among a subset of subjects, e.g., work psychosocial factors; therefore, some sample sizes in Table 2 are smaller than others. The three nerve latency variables were moderately to strongly correlated (median sensory latency to median motor latency, $R^2 = 0.68$; median sensory latency to MUD, $R^2 = 0.84$; median motor latency to MUD, $R^2 = 0.63$.

Adjusted regression models for median sensory latency outcome measures are presented in Table 3. Among the demographic variables, statistically significant associations were observed between median sensory latency and age, gender and BMI. The effect size of BMI was moderate (Cohen'd = 0.59). There was no significant relationship between previous distal upper extremity disorder and latency. Among the psychosocial variables, decision latitude was significantly associated with *shorter* latency, indicating better nerve function with greater decision latitude, although the effect size was small (Cohen's d = 0.031). Statistically significant adjusted associations were observed between both worker and analyst estimates of peak hand force and median sensory latency with greater forces associated with longer latency ($\text{Coefficient}_{\text{worker rated force}} = 0.03$, $p<0.001$; $\text{Coefficient}_{\text{analyst rated force}} = 0.03$, $p<0.001$). The effect sizes were small with a Cohen's d for Worker Rated Peak Force of 0.15 and Cohen's d for Analyst Rated Peak Force of 0.14. Of the three measures of repetition, only the Forceful Repetition Rate obtained from video analysis was significantly positively associated with median sensory latency ($\text{Coefficient}_{\text{forceful repetition rate}} = 0.003$, $p=0.01$). Among duty cycle measures, only Percent Duration Forceful Exertions was significantly associated with latency ($\text{Coefficient}_{\text{percent duration forceful exertions}} = 0.002$, $p=0.007$). The effect size was small. No association between either posture measure or vibrating tool use and sensory latency was observed. Finally, a significant association was observed between the TLV for HAL (using the analyst peak force rating) and sensory latency. The adjusted R^2 for the models ranged from 0.20 to 0.23.

Adjusted regression models for median motor latency outcome measure are presented in Table 4. As was observed for median sensory latency, age, gender, and BMI were significantly associated with median motor latency. Contrary to the results of median sensory latency, neither of the work psychosocial variables was significantly associated with motor latency. Both metrics of peak hand force were associated with median motor latency with coefficients and effect sizes of similar magnitude to their associations with median sensory latency ($\text{Coefficient}_{\text{worker rated force}} = 0.04$, $p<0.001$; $\text{Coefficient}_{\text{analyst rated force}} = 0.04$, $p<0.001$). The effect sizes were small ($\text{Cohen's d}_{\text{worker rated force}} = 0.13$; $\text{Cohen's d}_{\text{analyst rated force}} = 0.11$). Significant but small associations were also observed for the repetition measures of Analyst HAL and forceful repetition rate from video analysis, the posture measure of percent time >= 30 degrees of wrist extension, and the composite TLV for HAL. No Cohen's d value exceeded 0.05 for any of these associations. No significant associations were observed for percent duration of forceful exertions, percent duration of all exertions, or percent time >= 30 degrees wrist flexion. The adjusted R^2 for the models ranged from 0.18 to 0.20.

Adjusted regression models for median-ulnar latency difference measures are presented in Table 5. As was observed for median sensory latency and median motor latency, age, gender, and BMI were each significantly associated with median-ulnar latency difference. Among the psychosocial variables, decision latitude was significantly *negatively* associated with median-ulnar latency difference, although the effect size was small ($\text{Coefficient}_{\text{decision latitude}} = -0.004$, $p=0.02$; Cohen's d = 0.03). As was observed for the other two outcomes, Forceful Repetition Rate obtained from video analyses was significantly associated with median-ulnar latency difference ($\text{Coefficient}_{\text{forceful repetition rate}} = 0.003$, $p=0.01$). Among duty cycle measures, only percent duration forceful exertions was significantly associated with latency (Coefficient $_{\text{percent duration forceful exertions}}$ = 0.002, p<0.001); the effect size was small. Among the posture measures, percent time >=30 degrees wrist extension was significantly associated with median-ulnar latency difference. The TLV for HAL was also significantly associated with the median-ulnar latency difference. The adjusted R^2 for the models ranged from 0.11 to 0.13.

DISCUSSION

This study presents a unique analysis of associations between personal and work-related factors and an objective, quantitative metric of nerve physiology, median nerve conduction across the wrist. Most recent studies of risk factors for CTS among working populations have used a case definition requiring both a prolonged median nerve latency across the wrist and the reporting of symptoms in the distribution of the median nerve as the outcome measure (Gell et al, 2005; Werner et al. 2005; Silverstein et al. 2010; Harris-Adamson et al. 2013; Bonfiglioli et al., 2013). Although methodologically orthodox (Rempel et al. 1998), this approach may result in differential error due to reporting bias, with highly exposed participants possibly over-reporting hand symptoms in comparison to less highly exposed participants. Should such bias occur, it would result in observed associations that are stronger than true associations. For example, if workers who perform very repetitive hand activities report hand symptoms related to arthritis or cuts more frequently than others they might be misdiagnosed as having CTS, in which case, the resultant risk estimate for repetition and CTS would be higher than the true estimate.

The use of a physiological measure of median nerve function (a measure that requires no subjective response by the study participant), collected by technicians unaware of participant exposure, is unlikely to be characterized by differential error of the kind that may occur with symptom surveys. However, relatively few studies have analyzed median nerve function this way (Nathan et al, 1992; Letz & Gerr, 1994; Bushbacher, 1998; Salerno et al, 1998; Anton et al, 2013), in part because in many studies median nerve function is only measured among the subset of workers with hand symptoms (Stevens et al, 2001; Gerr et al., 2002; Gelfman et al, 2009).

In addition to use of a quantitative, objective physiological measure of median nerve function, the current study also involved a large population of workers from various industries across the US and participants were substantially representative of the age, gender, race and ethnicity of US workers. Therefore, the findings are more generalizable to the US workforce than studies of just one industry (Nathan et al. 1992; Gerr et al. 2002).

Personal factors had varied effects on sensory latency, motor latency, and MUD. Medium to large positive effects were observed for age, BMI and female gender (i.e., greater age and BMI and female gender were all associated with longer median nerve conduction latency). Personal factors not significantly related to latency were previous distal upper extremity disorders, education level, and aerobic or hand intensive activity outside of work. Mostly consistent with the current study, prior population and workplace studies have reported positive associations between height, BMI (or weight), age, gender, poverty, and smoking with median motor or sensory conduction measures (Nathan et al 1992; Letz & Gerr 1994;

Bushbacher 1998; Salerno et al. 1998; Anton 2013). The linear parameter estimates for age and estimated latency from the all male study of Letz & Gerr (1994) (0.011 to 0.013 ms/year) were similar to our study (0.007 to 0.017 ms/year). However, their parameter estimates for BMI (kg/m^2) were wider (0.0007 to 0.0065 ms/BMI unit) than those observed in our study (0.002 to 0.003 ms/BMI unit).

Several occupational factors were significantly associated with prolongation of median nerve latency measures. Significant associations, in decreasing order of effect size, were analyst and worker estimated peak hand force, video quantified percent duration of forceful hand exertions, TLV for HAL, video quantified forceful repetition rate, video quantified wrist extension, and low decision latitude. Work related factors that were not significantly associated with latency were psychological demand, total repetition rate, wrist flexion, duty cycle for all hand exertions, and vibration. Few studies have evaluated the associations of workplace factors and latency (Nathan et al, 1992). The Nathan et al. (1992) study found no associations with latency, but the precision of workplace exposure estimates was poor (Gerr & Letz, 1992) and the sample size was much smaller (N=316). Although the effect sizes were not large, our study shows associations between occupational exposures and nerve physiology. These results clearly demonstrate that workplace physical exposures are associated nerve conduction abnormalities characteristic of carpal tunnel syndrome.

In general, associations observed in the current study using median nerve latency measures as the health outcome are similar to recent high quality workplace studies that used a more clinical case definition of carpal tunnel syndrome that includes both symptoms and prolonged median nerve latency. For example, a recent prospective study of 3860 workers found that age, gender, BMI, co-morbid medical conditions and TLV for HAL were independent predictors of CTS (Bonfiglioli et al, 2013).

Our study found relatively little difference in the strength of association across the three median nerve latency measures for age, gender, BMI, and occupational biomechanical factors. An exception was that MUD was more sensitive to changes in BMI and less sensitivitive to gender compared to the other latency measures. Overall, the association coefficients and effect sizes (Cohen’s d) were similar in direction and magnitude across the three metrics of median nerve function. This might be expected given the strong correlations between the three latency measures as noted above. Interestingly, inspection of the adjusted R^2 values for the models suggests that the proportion of variance of the outcomes attributable to the independent variables is greatest for sensory latency, slightly smaller for motor latency, and smallest for MUD.

Several limitations of the study should be noted. Although the data were collected during prospective studies of workers, the duration of follow-up for the prospective component was too brief to observe important changes in median nerve latency measures. Therefore, the analysis used each subjects’ final median nerve latency measures as the outcome of interest. A longer duration of follow-up might have allowed for a study of change in latency measures over time. The use of nerve conduction latency alone may be questioned. However, this study sought to specifically exclude subjective symptom reporting from the disease outcome. A second limitation was that the workplace exposure assessment relied on both analyst observations and video analysis from recordings of one day of work. To the extent that the day observed was not representative of usual work there may be non-differential exposure misclassification. This would bias the findings toward the null and, therefore, the actual associations with workplace physical factors may be greater than those reported. Finally, the lack of an association for vibration should be interpreted with caution because the assessment was crude (e.g., Yes/No). Studies with more precise measures of vibration have found associations between vibration and risk of CTS (Koskimies et al, 1990).

Due to their large effect sizes, some readers may conclude that personal factors are more important than occupational factors in the etiology of CTS. We believe that such inferences should be made with caution. Age, BMI, and gender were all measured with extraordinarily high precision and accuracy. Error in these metrics is very low. On the other hand, measures of forceful exertions, repetitive exertions, and postural deviations are not easily measured and are never measured continuously over long time periods (i.e., durations similar to the time necessary for physiological changes in nerve physiology to occur). Hence, substantial non-differential error in estimation of these occupational risk factors was likely. Despite this bias toward the null, statistically significant associations between measures of exposure to occupational factors and median nerve physiology were still observed.

In conclusion, this analysis evaluated associations between personal and workplace factors and a physiologic outcome related to carpal tunnel syndrome instead of the more commonly used subjective clinical case definition. In a large and diverse working population, decrements in the three measures of median nerve latency were associated with age, BMI and gender as well as the workplace factors of peak hand force and percent duration of forceful hand exertions. The effect of workplace exposures to the upper quartile of hand force (Borg CR10 > 4), compared to the lower quartile, were similar to the effect of 6 to 11 years of aging (calculated from the parameter estimates of each exposure variable and each latency outcome). This means that workers who regularly perform hand activities with a Borg exertion rating of greater than 4, will, over time, experience a decline in their nerve function that is equivalent to the decline due to 6 to 11 years of aging. Overall, the findings of the current study are similar to those of other epidemiologic studies that used a clinical case definition carpal tunnel syndrome as the outcome. We believe that when taken in the context of a largely positive literature, evidence shows that carpal tunnel syndrome (whether measured as a clinical entity or with pure neurophysiological methods) is associated with both occupational and non-occupational factors. Resources should be directed towards intervention efforts designed to mitigate the known occupational risk factors for this condition.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

Anton D, Gerr F, Merlino L, Rosecrance JC. Normative median and ulnar nerve conduction values among a rural aged population. Work. 2013 (Epub ahead of print).

Bernard B. Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders.

Bonfiglioli R, Mattioli S, Armstrong TJ, Graziosi F, Marinelli F, Farioli A, Violante FS. Validation of ACGIH TLV for hand activity level in the OCTOPUS cohort: a two-year longitudinal study of carpal tunnel syndrome. Scand J Work Environ Work Environ Health. 2013; 39(2):155–163.

Bushbacher RM. Body mass index effect on common nerve conduction study measurements. Muscle Nerve. 1998; 21(11):1398–404. [PubMed: 9771662]

Bureau of Labor Statistics. Labor Force Statistics from the Current Population Survey. 2014. Table 11. Employed persons detailed by occupation, sex, race, and Hispanic or Latino ethnicity.

Chiang HC, Ko YC, Chen SS, et al. Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry. Scand J Work Environ Health. 1993; 19(2):126–31. [PubMed: 8316780]

Cohen, J. Statistical power analysis for the behavioral sciences. 2. Hillsdale, NJ: Erlbaum; 1988.

Dale AM, Harris-Adamson C, Rempel D, Gerr F, Hegmann K, Silverstein B, Burt S, Garg A, Kapellusch J, Merlino L, Thiese MS, Eisen EA, Evanoff B. Prevalence and incidence of carpal tunnel syndrome in US working populations: Pooled analysis of six prospective studies. Scand J Work Environ Health. 2013; 39(5):495–505. [PubMed: 23423472]

DeKrom M, Knipschild PG, Kester ADM, Thijs CT, Boekkooi PF, Spaans F. Carpal tunnel syndrome – prevalence in the general-population. J Clin Epidemiol. 1992 Apr; 45(4):373–6. [PubMed: 1569433]

Faucett J, Blanc P, Yelin E. The impact of carpal tunnel syndrome on work status: Implications of job characteristics syndrome on work status: Implications of job characteristics for staying on the job. J Occup Rehab. 2000; 10(1):55–69.

Foley M, Silverstein B, Polissar N. The economic burden of carpal tunnel syndrome: long-term earnings of CTS claimants in Washington State. Am J Ind Med. 2007 Mar; 50(3):155–72. [PubMed: 17216630]

Fung BK, Chan KY, Lam LY, et al. Study of wrist posture, loading, repetitive motion as factors for developing carpal tunnel syndrome. Hand Surg. 2007; 12(1):13–8. [PubMed: 17613179]

Gelfman R, Melton LJ, Yawn BP, Wollan PC, Amadio PC, Stevens JC. Long-term trends in carpal tunnel syndrome. Neurology. 2009; 72:33–41. [PubMed: 19122028]

Gell N, Werner RA, Franzblau A, Ulin SS, Armstrong TJ. A longitudinal study of industrial and clerical workers: Incidence of carpal tunnel syndrome and assessment of risk factors. J Occup Rehab. 2005; 15(1):47–55.

Gerr F, Letz R. Risk factors for carpal tunnel syndrome in industry: blaming the victim [Letter]. J Occup Med. 1992; 34(11):1117–9. [PubMed: 1432304]

Gerr F, Marcus M, Ensor C, et al. A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders. Am J Ind Med. 2002; 41(4):221–25. [PubMed: 11920966]

Harris-Adamson C, Eisen EA, Dale AM, et al. Personal and Workplace Psychosocial Risk Factors for Carpal Tunnel Syndrome: A Pooled Study Cohort. Occup & Environ Medicine. 2013; 70(8):529–37.

Harris-Adamson C, Eisen EA, Dale AM, et al. Biomechanical risk factors for carpal tunnel syndrome: A pooled study of production and service workers. Occup Environ Med. (in review).

Karasek R, Brisson C, Kawakami N, et al. The Job Content Questionnaire (JCQ): an instrument for internationally comparative assessments of psychosocial job characteristics. J Occup Health Psychol. 1998; 3:322–55. [PubMed: 9805280]

Kapellusch J, Garg A, Bao S, et al. Pooling job physical exposure data from multiple independent studies in a consortium study of carpal tunnel syndrome. Ergonomics. 2013; 56(6):1021–1037. [PubMed: 23697792]

Koskimies K, Farkklla M, Pyykko I, Jantti V, Aatola S, Starck J, Inaba R. Carpal tunnel syndrome in vibration disease. Br J Ind Med. 1990; 47:411–416. [PubMed: 2378818]

Letz R, Gerr F. Covariates of human peripheral nerve function: I. Nerve conduction velocity and amplitude. Neurotoxicol Teratol. 1994; 16(1):95–104. [PubMed: 8183195]

Nathan PA, Keniston RC, Myers LD, Meadows KD. Obesity as a risk factor for slowing of sensory conduction of the median nerve in industry: A cross-sectional and longitudinal study involving 429 workers. J Occup Med. 1992; 34(4):379–83. [PubMed: 1564575]

Maghdoudipour M, Moghimi S, Dehghaan F, Rahimpanah A. Association of occupational and non-occupational risk factors with the prevalence of work related carpal tunnel syndrome. J Occup Rehabil. 2008; 18(2):152–6. [PubMed: 18418702]

Palmer KT, Harris EC, Goggon D. Carpal tunnel syndrome and its relation to occupation: a systematic literature review. Occup Med. 2007; 57:57–66.

Rempel D, Evanoff B, Amadio PC, de Krom M, Franklin G, Franzblau A, Gray R, Gerr F, Hagberg M, Hales T, Katz JN, Pransky G. Consensus criteria for the classification of carpal tunnel syndrome in epidemiologic studies. Am J Public Health. 1998; 88:1447–1451. [PubMed: 9772842]

Salerno DF, Franzblau A, Werner RA, Bromberg MB, Armstrong TJ, Albers JW. Median and ulnar nerve conduction studies among workers: normative values. Muscle Nerve. 1998; 21(8):999–1005. [PubMed: 9655117]

Silverstein BA, Fine LJ, Armstrong TJ. Occupational factors and carpal tunnel syndrome. Am J Ind Med. 1987; 11(3):343–58. [PubMed: 3578290]

Silverstein BA, Fan ZJ, Bonauto DK, Bao S, Smith CK, Howard N, Viikari-Juntura E. The natural course of carpal tunnel syndrome in a working population. Scand J Work Environ Health. 2010; 36(5):384–393. [PubMed: 20352175]

Stevens JC, Witt JC, Smith BE, Weaver AL. The frequency of carpal tunnel syndrome in computer users at a medical facility. Neurology. 2001; 56:1568–1570. [PubMed: 11402117]

Werner RA, Franzblau A, Gell N, Hartigan AG, Ebersole M, Armstrong TJ. Incidence of carpal tunnel syndrome among automobile assembly workers and assessment of risk factors. J Occup Environ Med. 2005; 47:1044–1050. [PubMed: 16217245]

Table 1

Demographic characteristics of study population.

	N=2396	%
Gender		
Male	1122	47%
Female	1274	53%
Age (years)		
< 30 years of age	469	20%
≥ 30 & <40 years of age	603	25%
≥ 40 & <50 years of age	766	32%
≥ 50 years of age	558	23%
Ethnicity		
Caucasian	1133	47%
Hispanic	548	23%
African American	178	7%
Asian	145	6%
Other	75	3%
Education		
Some Highschool or less	509	21%
Highschool Graduate or above	1871	78%
Handedness		
Left Handed	187	8%
Right Handed	2209	92%
Body Mass Index		
Body Mass Index (<25)	734	31%
Body Mass Index (≥25 & <30: Overweight)	807	34%
Body Mass Index (≥30: Obese)	844	35%
General Health		
Very Good or Excellent	961	40%
Good	969	40%
Fair or Poor	315	13%
Medical Condition		
No Medical Condition	2102	88%
Current Medical Condition	290	12%
Diabetes	103	4%
Rheumatoid Arthritis	59	3%
Thyroid Disease (hyper/hypo)	133	6%
Pregnancy	18	1%
Previous Distal Upper Extremity Disorder		
No previous DUE	1658	69%

	N=2396	**%**
Previous DUE	286	12%
Smoking Status		
Never Smoked	1282	54%
Currently Smokes	588	25%
Previously Smoked	513	21%
Years Worked at Enrollment		
>1 year & ≤ 3 years	536	22%
>3 years & ≤ 7 years	631	26%
>7 years & ≤12 years	623	26%
>12 years	426	18%

Table 2

Summary of job exposure values (TWA) and median nerve latency measures.

BIOMECHANICAL MEASURES	**N**	**Mean**	**S.D.**	**Median**	**IQR**
FORCE MEASURES					
Peak Force:Worker rated Borg CR10	2119	3.5	2.2	3.3	2 – 5
Peak Force: Analyst rated Borg CR10	2279	3.0	1.8	3.0	1.3 – 4
REPETITION MEASURES					
Analyst HAL Rating	2286	4.8	1.7	4.9	4 – 6
Total Repetition Rate	2289	24.3	19.2	18.1	10.5 – 32
Forceful Repetition Rate	2289	9.4	13.5	4.3	1.1 – 10.4
DUTY CYCLE					
% Duration All Exertions	2289	66.6	19.3	68.0	54.8 – 80.6
% Duration Forceful Exertions	2289	22.6	20.3	17.3	5.6 – 35.3
POSTURE MEASURES					
% Time ≥30° Wrist Extension	2272	15.1	22.4	5.0	0 – 20
% Time ≥30° Wrist Flexion	2272	3.2	6.8	0.4	0 – 3.7
OTHER					
Vibration (N/Y)	1972	0.34			0 – 1
COMPOSITE MEASURES					
TLV for HAL (Analyst Peak Force)	2238	0.70	0.61	0.57	0.29 – 0.86
WORK PSYCHOSOCIAL MEASURES					
Psychological Demand Scale	1410	31.39	4.87	31.00	28 – 34
Decision Latitude	1403	61.04	9.10	62.00	56 – 66
LATENCY MEASURES					
Median Sensory Latency	2326	3.578	0.625	3.448	3.15 – 3.85
Median Motor Latency	2367	3.929	0.926	3.800	3.40 – 4.22
Sensory Med-Ulnar Difference	2257	0.467	0.532	0.288	0.12 – 0.60

Table 3

Linear regression models for median sensory latency with work psychosocial or biomechanical exposures. Models adjusted for age, gender, BMI, study site and the job physical exposures identified in the table.

	N	Coefficient	p-value	Cohen’s d
Age	2315	0.015	0.000	0.400
Gender (female)		0.049	0.043	
BMI		0.022	0.000	0.593
Work Psychosocial Variables (adj. for peak force, total repetition rate, % duration all exertions, % time ≥ 30° wrist flexion)				
Psychological Demand	1052	0.003	0.322	0.016
Decision Latitude	1050	−0.005	0.010	−0.031
Biomechanical Exposures				
FORCE MEASURES (adj. for total repetition rate, % duration all exertions, % time ≥30° wrist flexion)				
Peak Force: Worker Rated	1982	0.031	0.000	0.151
Peak Force: Analyst Rated	2139	0.033	0.000	0.141
REPETITION MEASURES (adj. for peak force, % time ≥ 30° wrist flexion)				
Analyst HAL Rating	2121	0.013	0.111	0.041
Total Repetition Rate: Video	2139	0.002	0.130	0.055
Forceful Repetition Rate: Video *	2196	0.003	0.011	0.041
DUTY CYCLE (adj. for peak force, % time ≥30° wrist flexion)				
% Duration All Exertions	2139	0.001	0.132	0.042
% Duration Forceful Exertions *	2196	0.002	0.007	0.079
POSTURE MEASURES (adj. peak force, total repetition rate, % duration all exertions)				
% Time ≥ 30° wrist extension	2139	0.000	0.647	0.009
% Time ≥ 30° wrist flexion	2139	−0.002	0.253	−0.012
OTHER MEASURES (adj. for peak force, total repetition rate, % duration all exertions, % time ≥ 30° wrist flexion)				
Vibrating power tools used	1874	0.012	0.698	0.019
COMPOSITE MEASURES (adj. for % time ≥ 30° wrist flexion)				
TLV for HAL (Analyst Peak Force)	2108	0.060	0.006	0.055

*only adjusted for posture (flexion)

Table 4

Linear regression models for median motor latency and work psychosocial exposure or TWA biomechanical exposures. Adjusted models include age, gender, BMI, study site and selected job physical exposures.

	N	Coefficient	p-value	Cohen's d
Age	2356	0.017	0.000	0.308
Gender (female)		0.136	0.000	
BMI		0.032	0.000	0.594
Work Psychosocial Variables (adj. for peak force, total repetition rate, % duration all exertions, % time ≥ 30° wrist flexion)				
Psychological Demand	1059	−0.002	0.755	−0.005
Decision Latitude	1057	−0.003	0.253	−0.014
Biomechanical Exposures				
FORCE MEASURES (adj. for total repetition rate, % duration all exertions, % time ≥30° wrist flexion)				
Peak Force: Worker Rated	2019	0.041	0.000	0.133
Peak Force: Analyst Rated	2175	0.037	0.000	0.109
REPETITION MEASURES (adj. for peak force, % time ≥ 30° wrist flexion)				
Analyst HAL Rating	2157	0.025	0.041	0.054
Total Repetition Rate: Video	2175	0.002	0.185	0.049
Forceful Repetition Rate: Video *	2233	0.004	0.019	0.039
DUTY CYCLE (adj. for peak force, % time ≥ 30° wrist flexion)				
% Duration All Exertions	2175	0.001	0.174	0.039
% Duration Forceful Exertions *	2233	0.001	0.137	0.045
POSTURE MEASURES (adj. peak force, total repetition rate, % duration all exertions)				
% Time ≥ 30° wrist extension	2175	0.002	0.020	0.045
% Time ≥ 30° wrist flexion	2175	0.001	0.595	0.006
OTHER MEASURES (adj. for peak force, total repetition rate, % duration all exertions, % time ≥ 30° wrist flexion)				
Vibrating power tools used	1909	−0.060	0.224	−0.065
COMPOSITE MEASURES (adj. for % time ≥ 30° wrist flexion)				
TLV for HAL (Analyst Peak Force)	2144	0.082	0.016	0.050

* only adjusted for posture (flexion)

Table 5

Linear regression models for median-ulnar sensory latency difference and work psychosocial exposure or TWA biomechanical exposures. Adjusted models include age, gender, BMI, study site and selected job physical exposures.

	N	Coefficient	p-value	Cohen's d
Age	2246	0.007	0.000	0.228
Gender (female)		−0.030	0.171	
BMI		0.025	0.000	0.806
Work Psychosocial Variables (adj. for peak force, total repetition rate, % duration all exertions, % time ≥ 30° wrist flexion)				
Psychological Demand	1029	0.003	0.301	0.018
Decision Latitude	1027	−0.004	0.015	−0.031
Biomechanical Exposures				
FORCE MEASURES (adj. for total repetition rate, % duration all exertions, % time ≥30° wrist flexion)				
Peak Force: Worker Rated	1922	0.026	0.000	0.147
Peak Force: Analyst Rated	2078	0.030	0.000	0.150
REPETITION MEASURES (adj. for peak force, % time ≥ 30° wrist flexion)				
Analyst HAL Rating	2061	0.010	0.189	0.036
Total Repetition Rate: Video	2078	0.001	0.278	0.042
Forceful Repetition Rate: Video *	2129	0.003	0.009	0.045
DUTY CYCLE (adj. for peak force, % time ≥ 30° wrist flexion)				
% Duration All Exertions	2078	0.001	0.218	0.036
% Duration Forceful Exertions *	2129	0.002	0.000	0.120
POSTURE MEASURES (adj. peak force, total repetition rate, % duration all exertions)				
% Time ≥ 30° wrist extension	2078	0.000	0.417	−0.016
% Time ≥ 30° wrist flexion	2078	−0.001	0.510	−0.008
OTHER MEASURES (adj. for peak force, total repetition rate, % duration all exertions, % time ≥ 30° wrist flexion)				
Vibrating power tools used	1831	−0.013	0.652	−0.024
COMPOSITE MEASURES (adj. for % time ≥ 30° wrist flexion)				
TLV for HAL (Analyst Peak Force)	2048	0.054	0.007	0.057

*only adjusted for posture (flexion)