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A prospective study of carpal tunnel syndrome: workplace and individual risk factors

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Abstract

Objectives—To quantify the risk for carpal tunnel syndrome (CTS) from workplace physical factors, particularly hand activity level and forceful exertion, while taking into account individual factors including age, gender, body mass index (BMI), and pre-existing medical conditions.

Methods—Three healthcare and manufacturing workplaces were selected for inclusion on the basis of range of exposure to hand activity level and forceful exertion represented by their jobs. Each study participants job tasks were observed and evaluated ' onsite and videotaped for further analysis, including frequency and duration of exertion and postural deviation. Individual health assessment entailed electrodiagnostic testing of median and ulnar nerves, physical examination and questionnaires at baseline with annual follow-up for 2 years.

Results—The incidence of dominant hand CTS during the study was 5.11 per 100 person-years (29 cases). Adjusted HRs for dominant hand CTS were as follows: working with forceful exertion ≥20% but <60% of the time: 2.83 (1.18, 6.79) and ≥60% of the time vs <20%: 19.57 (5.96, 64.24), BMI ≥30 kg/m^2 (obesity): 3.19 (1.28, 7.98). The American Conference for Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) for hand activity level also predicted CTS, HR=1.40 (1.11, 1.78) for each unit increase in the TLV ratio, controlling for obesity and job strain.

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Contributors SB planned, initiated, oversaw data collection and analysis and wrote the article. JAD and YJ conducted statistical analysis. KC and JR oversaw exposure data collection and reduction. SW completed exposure data reduction.

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Conclusions—Workplace and individual risk factors both contribute to the risk for CTS. Time spent in forceful exertion can be a greater risk for CTS than obesity if the job exposure is high. Preventive workplace efforts should target forceful exertions.

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most commonly reported entrapment neuropathy of the upper limb.[12] Its effects on workers can be chronically debilitating both in the workplace and in their personal lives.[3] The economic consequences are felt by workers, employers and insurers. CTS is among the greatest drivers of workers' compensation costs, lost time, lost productivity and disability.[45] Many of these disorders could be prevented by identifying hazardous jobs and redesigning job tasks, tools and workstations to reduce physical stressors. A conceptual model describing the complex interaction of work requirements (exposure) leading to the doses (eg, physical loads) and responses (eg, tissue thickening) that can result in upper limb musculoskeletal disorders when tolerance (capacity) is exceeded was an organising theme for this study.[6] Research has demonstrated associations between repetitive and forceful hand activity, non-neutral wrist postures and hand-arm vibration at work and CTS.[7] Individual risk factors for CTS include age, gender, body mass index (BMI), pregnancy and other medical conditions, such as diabetes and thyroid disorders.[8] A comprehensive review of the literature on work-related musculoskeletal disorders by NIOSH noted that exposure-response relationships were difficult to determine across studies due to a wide range of exposure assessment methods, different health outcome definitions and a restricted range of exposures in the jobs studied and other methodological issues.[7] A more recent review suggests that there is still little guidance on the level of exposure to physical work demands that is associated with CTS.[9] Limitations of past studies, including a lack of precision of estimation of potentially hazardous exposures, a lack of individual exposure assessment, a limited range of exposure variation, or cross-sectional study design have hindered attempts at exposure-response analysis.

The primary aim of this study is to quantify the relationship between recognised workplace physical factors, particularly repetitive or prolonged hand activity and forceful exertion, and CTS, while taking into account individual factors as well as psychosocial/work organisational factors such as job strain.

METHODS

Potential study plants were identified from those who had volunteered to participate following announcement of the study in the Federal Register and communication with occupational safety and health professionals on the National Occupational Research Agenda (NORA I) Musculoskeletal Team. Workplaces were selected to represent a range of the two primary exposures of interest: repetitive or prolonged hand activity, and forceful exertion. During initial walkthrough evaluations, ergonomists used checklists to determine exposure categories of jobs. Selected workplaces had jobs that represented at least three of six exposure categories that combined low, medium, or high hand activity level (HAL) with low or high force. Additional workplace selection criteria included at least 100 employees and no anticipated lay-offs or major changes in production or reorganisation. Three worksites were selected: a hospital, a school bus manufacturing plant and an engine assembly plant. All full-time workers with at least 3 months on the job in selected departments were invited to participate in the study. Because of the detailed exposure assessment required, we excluded jobs with more than four different tasks, jobs that were too varied to characterise (eg, most maintenance jobs), or that could not easily be videotaped for subsequent analysis (eg, fork lift drivers). Prevalent CTS cases and those with polyneuropathy that were identified during the baseline cross-sectional study were excluded from the longitudinal study.[10] The longitudinal study presented here included two follow-up exposure and health data collection visits 1 and 2 years after the baseline assessment. Interim visits to evaluate job changes, if they occurred, were made 6 months following the baseline and first annual full data collection visits. The prospective study population included 347 participants (figure 1). At the hospital, 120 workers from central and sterile supply, laboratory, pharmacy, engineering, surgical, kitchen, laundry and administrative support participated. In the engine plant, 70 workers in assembly, machining, quality control and manufacturing support were included. In the bus plant, 157 workers from assembly, sub-assembly, conveyor, machine fabrication, electrical, upholstery, engineering and transport jobs were included. Follow-up participation rates were 83% for at least 1 year of follow-up data collection beyond the baseline and 77% for both years. Fifty-six workers did not complete the study because they left employment, were absent from work or unavailable during the weeks of the annual data collection visits, or declined follow-up participation. Following approval by the NIOSH Institutional Review Board and written informed consent, each study participant underwent detailed job exposure assessment including direct observation and videotaping of job tasks, physical examination of the upper limbs, and nerve conduction testing of the median and ulnar nerves across the wrist. A detailed questionnaire was administered to collect information on work history, individual factors, work environment, physical activities outside of work and medical history, as well as neck, shoulder, arm and hand symptoms, including a hand diagram documenting type and location of symptoms.[11–15] Height and weight were measured. Participation in the study took place during working hours and was not compensated. Study participants were notified of their own health assessment results, interpretation and recommendations by mail. Employers were given group results that were not individually identifiable. The exposure assessment team was blinded to study participants' health information, and the health assessment team was blinded to exposure information.

Field exposure data collection

For each study participant, a NIOSH ergonomist rated the HAL of each task on the HAL 10-point visual analog scale,[16] and determined whether the physical demands of the task reached a threshold of forceful exertion, defined as at least 8.9 N (2 lb) of pinch force or 44.5 N (10 lb) of power grip force. For forceful exertions, the ergonomist recorded additional observational exposure data including observer and worker ratings of perceived exertion (RPE) using a modified Borg CR-10 scale,[17] grip type, contact stress, and the presence or absence of hand-arm vibration. Workers were also asked to mimic the level of force and type of grip they used for specific tasks immediately after performing the task, using a power grip (Jamar, Bolingbrook, Illinois, USA) or pinch grip (Baseline, White Plains, New York, USA) dynamometer; ergonomists recorded these force-matching readings in pounds.[18,19] Each task was also videotaped by two cameras at different angles for later analysis. Single-task jobs were videotaped for at least 15 min; for multitask jobs, each task was videotaped for at least 10 min. These exposure assessment methods are as described by Bao *et al*.[20]

Laboratory exposure analysis

Five 1-min segments of digitised video were randomly selected for analysis for each single-task job and three 1-min segments for each task in a multitask job. Trained analysts then used the Multi-Media Video Task Analysis (MVTA)[21] system to mark the start and end of each exertion following written criteria to facilitate applying the study definition of an exertion as at least 5% of maximum voluntary contraction (MVC) and each forceful exertion. Forceful exertions were defined during field observation and identified on video by matching the tools, actions and objects viewed to photographs and written descriptions.

NIOSH researchers developed a computer-assisted, video-based method to analyse postural deviation from selected still frames from the same job task video segments used for the MVTA analysis. Trained raters viewed selected still frames and recorded postures of the neck, shoulder, elbow, forearm and wrist on each of 15 scales, using onscreen posture illustrations as a guide. For each participant, 75 still frames were analysed if it was a single task job, or 60 still frames for each task if the job involved multiple tasks. Ratings by physical therapy undergraduates with 3 h of training by an ergonomist resulted in intraclass correlation coefficients (ICC) ranging from 0.41 to 0.85; 11 of the 15 scales had ICCs >0.70.[22]

Exposure data reduction

Frequency, duration and percent time spent in regular and forceful exertions were calculated from data entered in MVTA, and field measurement data on RPE and force-matching values were linked to each forceful exertion. Job-level exposure variables were created by combining exposure data across tasks for each study participant to represent his or her entire job. Job-level peak variables represent the peak of all tasks. Job-level time-weighted average (TWA) variables, such as HAL ratings and force, were weighted by the percent time spent in each task. Raw force measurements (pounds) from field observations were normalised as a percent of the individual worker's % MVC, matching type of grip (pinch or power). Job-level TWA HAL ratings and force-matching peak values were used to obtain values for the American Conference for Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) and Action Limit (AL) for HAL.[23] Additionally, we calculated the threshold limit ratio, proposed by Drinkaus *et al*[24] as an alternative interpretation of the ACGIH TLV for HAL, which provides a continuous measure using the same inputs of peak force and average HAL. The TLV Ratio (TLR)=Force/(−0.78×HAL + 7.78) A TLR of 1 equals the TLV; a TLR of 2 is twice the TLV, and so on. This modification also applies to multitask jobs such as those in this study. If there was a job change during the course of the study, exposure variables were calculated (TWA or peak) across data collection visits, up until the time of case ascertainment.

Scales were created from the work environment questionnaire (psychological demands, supervisor support, coworker support, group pressure and depression) following published guidelines.[11] Job strain was defined as psychological demand/decision latitude after dichotomising each scale to create four categories (high, active, passive, low) (see online supplementary table).

Health assessment

Each study participant had an upper limb physical examination, completed questionnaires and recorded location and type of symptoms, if any, on hand diagrams. Regardless of whether or not symptoms were present, each participant underwent nerve conduction testing of the median and ulnar nerves at the wrist. All nerve conduction testing was performed by the same experienced registered electrodiagnostic technician according to published guidelines.[25] Median and ulnar sensory and median motor latencies and amplitudes were determined on both hands via standard techniques of supramaximal percutaneous nerve stimulation and surface recording using XLTEK NeuroMax1002 equipment (Oakville, Ontario, Canada). The distance between the stimulation and recording sites was 14 cm for the median and ulnar nerves across the wrist and 8 cm for both nerves for mid-palmar testing. Skin temperature was measured on the palm using a digital skin thermometer and, if necessary, the hand was warmed to obtain a temperature >32°C. Determinations of median mononeuropathy were provided by the technician following predetermined criteria (Washington State Department of Labor & Industry, Office of the Medical Director, 2001, personal communication). Additionally, NIOSH researchers blinded to the technician's results applied the same criteria using a SAS program, and results were compared. Issues were resolved by adopting decision rules, taking into account, for example, age and length of hands. Finally, nerve conduction tracings were reviewed by a neurologist to identify potential problems.

Case definition for CTS.

All the following criteria were required:

1. Met the electrodiagnostic criteria for median mononeuropathy (see box)
2. On the questionnaire, symptoms of numbness, tingling, burning, or pain were recorded
3. On the hand diagram, the above symptoms were recorded in the median nerve distribution

Electrodiagnostic criteria for median mononeuropathy: criteria 1 and (2 or 3)

Criterion 1 slowed latency in median nerve

- wrist to index finger sensory latency >3.7 ms or
- mid-palm to wrist sensory latency >2.2 ms or
- motor latency >4.4 ms

Criterion 2 normal distal ulnar nerve latency

- wrist to little finger sensory latency ≤3.7 ms

Criterion 3 distal median nerve latency > distal ulnar latency

- median wrist to index finger—ulnar wrist to little finger latency difference >1.0 ms or
- median mid-palm to wrist—ulnar mid-palm to wrist latency difference >0.5 ms

ms=milliseconds

Statistical analysis

Means, peaks and proportions were computed for descriptive statistics for all individual and workplace exposure variables. Univariate proportional hazards modelling was used to evaluate associations between individual and workplace exposure variables and incident dominant hand CTS. To reduce the number of exposure variables for analysis and to avoid problems caused by correlation among exposure variables, a limit of one variable was set to represent each of the three main exposure domains (hand activity, force and posture). Separate proportional hazard models were created for quantitative exposure variables and the ACGIH TLV. Multivariate models were built using a manual stepwise approach beginning with the primary exposure variable, then testing bivariate exposure models to determine whether the addition of a 2nd exposure variable improved the model. Then covariates that had univariate associations with CTS at the $p<0.1$ level (see online supplementary table) were tested in multivariate proportional hazards models, retaining those that either met the $p<0.05$ criterion or that changed the β coefficient of exposure by at least 10%. Two-way interactions were tested, using the same $p<0.05$ criterion for retention.

RESULTS

Demographics and pertinent prior medical history by case status are shown in table 1. Obesity and prior non-dominant hand CTS were significantly associated with incident-dominant hand CTS, while age and gender were not. Smoking, thyroid disease and rheumatoid arthritis were higher among cases, but the differences were not statistically significant. There were no diabetics among cases, probably because we excluded those with polyneuropathy and baseline CTS cases from the prospective analysis. We observed 29 incident cases of dominant hand CTS over the 2-year follow-up period of the study, an incidence rate of 5.11 per 100 person-years.

As shown in table 2, job exposures significantly associated with CTS included worker peak and average RPE, force matching, forceful exertions per second, percent time in forceful exertion, the ACGIH TLV for HAL as a ratio (but not the cutpoints at the TLV and AL) and job strain.

Proportional hazards multivariate modelling resulted in final models (table 3) that included the percent of time working with forceful exertion and the ACGIH TLV for HAL as a ratio. Obesity was a significant predictor of CTS in both models. Working in a high-strain job was not significantly associated with CTS in the first quantitative job exposure model, but it was in the TLV ratio model (table 3). Obesity was also a confounder of the association between the percent time in significant exertion and CTS. With obesity in the model, the estimate for forceful exertion increased by 15%. The test of interaction between obesity and forceful exertion was not statistically significant (p=0.07). A proportional hazards model with the ACGIH TLV for HAL (table 3) shows an increased HR for CTS of 1.4 for each unit increase in the TLV for HAL as a ratio (model 2). Each unit increase represents a multiple of the TLV (eg, TLR=2 is twice the TLV).

Figure 2 shows the exposure-response relationship between percent time in forceful exertion and CTS, adjusted for obesity. The association between the percent time spent working with forceful exertion and CTS appeared to be linear (figure 2). BMI was not significantly associated with CTS as a continuous variable, but obesity was when using the standard cutoff of 30 kg/m^2 (table 2).

DISCUSSION

Physical job demands represented by the percent of time spent in forceful exertion or the ACGIH TLV for HAL as a ratio, adjusted for obesity and job strain, predicted dominant hand CTS. Recent studies have shown exposure-response relationships between ratings-based metrics, such as the ACGIH TLV for HAL among industrial workers[26,27]; while an earlier study did not observe these relationships.[28,29] Garg *et al*[26] suggested the use of the TLV as a ratio if other researchers confirmed their findings that this is a useful metric; our study supports their suggestion. We are unaware of other prospective studies of CTS that reported exposure-response relationships with quantitative exposure measures such as percent time in forceful exertion based on detailed time studies of job tasks. Obesity also predicted CTS in our multivariate models. Proposed mechanisms for the impact of obesity on the carpal tunnel have not been fully developed, but some researchers suggest fatty tissue and/or swelling in the carpal tunnel impinges on the median nerve.[30] Obesity resulted in positive confounding of the association between physical job demands and CTS in this study, while in our cross-sectional study, obesity had a significant interaction with physical job demands.[10] In both studies, the end result is that if someone is both obese and has high physical job demands, the risk is increased beyond what it would be if only one of these risk factors were present. The association between high job strain and CTS was significant in the TLV ratio model but not in the quantitative exposure model based on percent time in forceful exertion. High psychological demand/low control jobs, as defined by Karasek to represent job strain, also were more likely to have high physical demands as represented by the percent of time spent working with high force in our study, so our data cannot adequately address these issues.

This prospective study of dominant hand CTS has identified an exposure-response relationship with physical job demands, controlling for individual and work organisational factors. The risk for CTS increases with an increased amount of time spent in forceful exertion. These results and prior results from our cross-sectional analysis suggest that force may be the primary job exposure risk factor for CTS. A reduction in the amount of time spent in forceful exertion and the intensity of the required force of job tasks may reduce the occurrence of CTS. Obesity also increased the risk for CTS in this study as in our prior cross-sectional analysis. A reduction in obesity may also reduce the risk for CTS.

Implications for job strain are not as clear. It is feasible to suggest that some of the jobs in this study that had high physical demands might also have offered workers little control, for example, over when they could take breaks and the pace of their work, and that these organisational factors may contribute to the risk for CTS. Although job strain has frequently been reported to be associated with upper limb musculoskeletal disorders in general, a comprehensive review of CTS studies found no associations between these or any psychosocial risk factors and CTS.[9] Two cohort studies that included both physical job stressors and psychosocial factors reported no association between psychological job demands or control and CTS.[31,32] Silverstein *et al* reported associations between CTS and psychological job demands in descriptive data, but the analysis did not control for physical job stressors.[33] Further research may clarify these relationships.

The CTS incidence rate of this study (5.11 per 100 person-years) is within the range reported by other prospective work-place studies. A similar prospective study of CTS by Silverstein *et al* reported a 1-year dominant hand CTS incidence rate of 7.5%,[33] and another prospective study of CTS by Garg *et al*[26] reported a 1-year CTS incidence rate of 2.55 per 100 person-years. Violante *et al*[34] reported a 1-year incidence of CTS of 7.3%, although the case definition differed from ours in that it did not require nerve conduction testing. Gell *et al*[28] reported a CTS incidence rate of 1.2% per year for a cohort of industrial and clerical workers over a 5-year period, but approximately 50% of their study group was lost to follow-up. Werner *et al*[29] reported a CTS incidence of 4.5% if the case definition required nerve conduction testing on the industrial cohort from the same study.

One of the challenges of a study like ours in which there is an abundance of detailed quantitative exposure data is how to reduce the raw data to summary exposure variables, and then how to select exposure variables for the final multivariate analyses. Our primary analysis used subtask level force and frequency of exertion data to determine peak and TWA exposures at the task level. It may be fruitful in future analyses to use the actual force and frequency required for particular exertions within each task. Another challenge is that the summary exposure variables are still numerous, and many of them are correlated with each other; with a relatively small number of study subjects, there is a need to reduce the number of variables analysed. We took the approach of limiting the variables for multivariate analysis to a maximum of one variable per ‘domain’ of exposure, with each domain representing either force (intensity of exertion), HAL (repetition, duration of exertion, etc), or posture (degree of postural deviation). Some combined variables were also analysed, such as the % time at different levels of exertion or postural deviation. We did not find significant associations between wrist posture and CTS, although it has been cited as a risk factor for CTS in other studies.[7,9,35] Our posture observations from video still frames may not be the best method to evaluate wrist posture; the inter-rater reliability of our posture observations was good for shoulder and arm postures, but lower for wrist postures.[10,22] It has also been demonstrated in past studies that wrist flexion and extension lead to increased carpal tunnel pressure, a proposed mechanism leading to CTS.[36] Neither did we find an association between vibration and CTS, although there is substantial evidence of this from prior studies.[7] Our study was designed to focus on HAL and forceful exertion, and the only vibration measure used here was the observation of whether a vibrating tool was being used or not. We selected jobs to provide a range of HAL and force since these were the primary exposures of interest. The lack of associations observed in our data for vibration and wrist posture should not be construed as evidence of no association between these risk factors and CTS.

The limitations of our study include a reduced sample size from the original study plan to include 1000 study subjects based on power and sample size calculations. Due to resource constraints, we needed to cut our sample size in half. We still were able to see significant results probably due to reduced mis-classification of exposure because of detailed individual quantitative exposure measures, and a relatively wide range of exposures among the jobs selected for the study. We selected jobs to represent a range of exposures to two primary risk factors—force and HAL. This study is part of a collaborative research effort, and analysis of pooled data from multiple research organisations is underway and may provide further answers to remaining questions on work-related CTS.

CONCLUSION

Multiple risk factors contribute to the occurrence of CTS. In the general population, the emphasis is usually on individual factors, such as age, gender, obesity and prior medical conditions, such as diabetes; these factors are easy to measure. However, general population studies do not take workplace exposures into account. High-quality workplace research studies require extensive effort and expense, particularly to collect detailed quantitative exposure measures at the task level and even at the level of specific events within tasks for each individual study participant, and to analyse the multitude of data that result. This study shows that when such efforts are taken, specific quantitative measures of job physical exposures, such as the time spent in forceful exertion, reveal significant risk for CTS that can be greater than individual risk factors if the job exposure is high. Summary measures of the physical demands of jobs, such as the ACGIH TLV for HAL, offer a more practical means of identifying jobs that represent higher risk for CTS and, possibly, other musculoskeletal disorders that share similar risk factors of a high level of hand activity and high force. For those who have both personal risk factors such as obesity, and high physical job demands, such as a high percent of time working with forceful exertion, the risk for CTS is greater than it would be if only one risk factor were present. In workplaces, preventive efforts should target job tasks that require a high level of force or a high percent of time working with force. Our study also supports the use of the ACGIH TLV for HAL (especially when expressed as a ratio) as a guide to targeting jobs for preventive interventions. Workplaces might also consider organisational factors that facilitate opportunities for healthier lifestyles, such as exercise and healthier food choices, that might reduce obesity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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What this paper adds

- There is little quantitative exposure-response data from prospective studies that could be used to provide guidance as to the level of exposure to physical work demands that leads to carpal tunnel syndrome.
- This study offers detailed quantitative exposure measures of each study participant over time and case definitions that include clinical electrodiagnostic testing.
- Quantitative exposure-response data and American Conference for Governmental Industrial Hygienists Threshold Limit Value analyses suggest levels of work demands that result in increased risk for carpal tunnel syndrome and that could be useful in targeting preventive efforts.

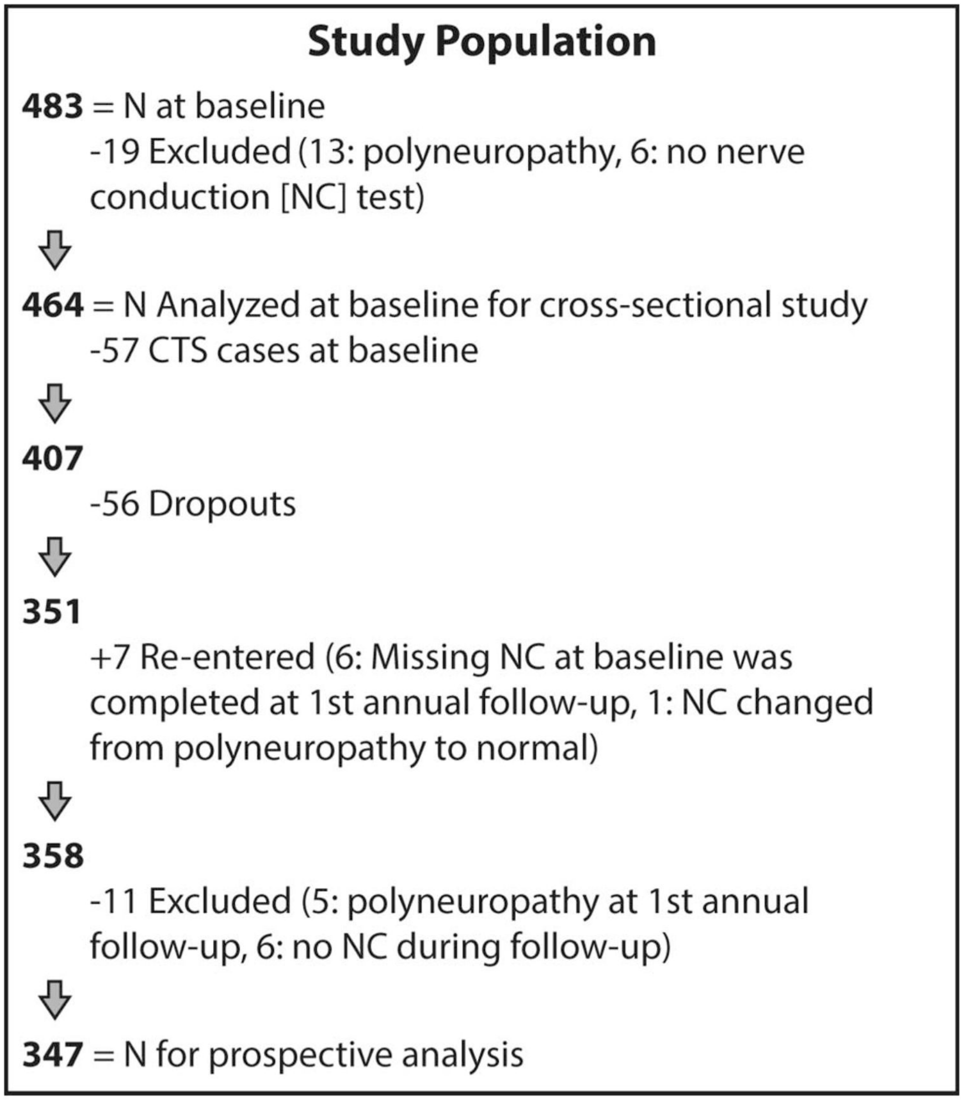

Figure 1.
Study population

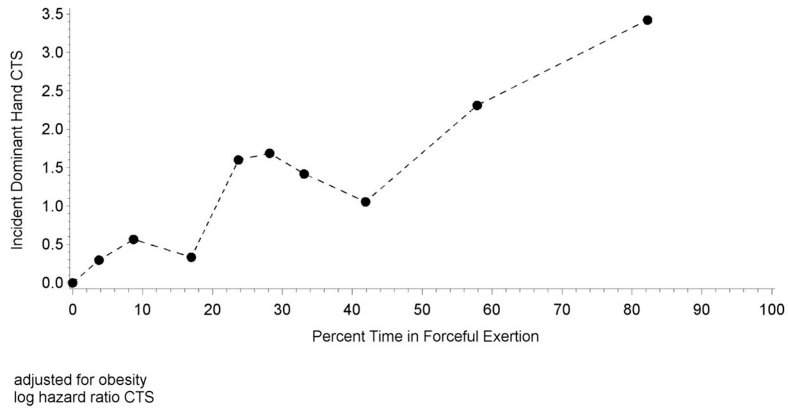

Figure 2.
Incident CTS by percent time in forceful exertion

Table 1

Characteristics of the study group

	Mean or number (%)				
	All (n=347)	Range (SD)	CTS non-cases (n=318)	CTS cases (n=29)	p Value (χ^2 or t test)
Gender					0.27
Male	201 (57.9)		53.9	48.3	
Female	146 (42.1)		46.1	51.7	
Age (years)	40.5	19–68 (10.7)	40.5 (10.5)	41.6 (12.3)	0.58
BMI (kg/m^2)	29.5	18.1–61.6 (6.3)	29.4 (6.4)	30.7 (4.8)	0.29
<30	201 (57.9)		60.1	34.5	
≥30	146 (42.1)		39.9	65.5	0.01
High school education	333 (96.0)		95.9	96.6	0.87
Current smoking	82 (23.6)		23.0	31.0	0.33
Diabetes	22 (6.3)		6.9	0.0	0.14
Thyroid disease	29 (8.4)		7.9	13.8	0.23
Prior non-dominant hand CTS	11 (3.2)		2.5	10.3	0.02
Years worked at plant	9.8	0.25–20 (8.1)	9.6 (8.1)	11.7 (8.0)	0.19

CTS, carpal tunnel syndrome.

Table 2

Job exposures by CTS case status

	Mean or number (%)				
	All n=347	**Range (SD)**	**CTS non-cases n=318**	**CTS cases n=29**	**p Value (χ^2 or t test)**
Observer RPE avg	2.8	1–6 (1.2)	2.8 (1.2)	3.1 (1.2)	0.11
Observer RPE peak	4.1	1–10 (1.9)	4.0 (1.9)	4.5 (1.7)	0.20
Worker RPE avg	2.6	0.7–7.8 (1.4)	2.6 (1.4)	3.2 (1.6)	0.01
Worker RPE peak	4.3	1–10 (2.5)	4.2 (2.5)	5.4 (2.4)	0.01
Force Match avg	3.9	0.5–11.4 (2.5)	3.8 (2.4)	4.9 (2.7)	0.02
Force Match peak	6.0	1–13.1 (3.5)	5.9 (3.5)	7.5 (3.5)	0.02
Exertions/min*	14.4	0.7–50.9 (9.2)	14.1 (9.1)	16.9 (10.4)	0.11
Forceful exertions/min*	4.1	0–34.1 (5.4)	4.0 (5.3)	6.0 (5.6)	0.05
%Time in exertion*	70.1	93.7–100 (18.7)	69.9 (18.5)	71.9 (20.6)	0.59
%Time in forceful exertion*	17.5	0–96.9 (18.7)	16.4 (17.8)	29.5 (24.4)	<0.01
0 to <20%	216 (63.3)		210 (66.0)	10 (34.3)	<0.001
20% to <60%	112 (32.8)		100 (31.4)	14 (48.3)	
60%+	13 (3.8)		8 (2.6)	5 (17.2)	
ACGIH TLV					0.32
<AL	102 (29.4)		97 (30.5)	5 (17.2)	
AL to TLV	10 (2.9)		9 (2.8)	1 (3.4)	
TLV+	235 (67.7)		212 (66.7)	23 (79.3)	
ACGIH TLV ratio (TLR)	1.53	0.13–7.52 (1.13)	1.50 (1.11)	2.09 (1.35)	<0.01
Observer HAL avg	4.2	0.1–8 (1.5)	4.1 (1.5)	4.6 (1.6)	0.09
Tabulated HAL avg	3.6	0.2–7 (1.7)	3.6 (1.7)	4.0 (1.6)	0.19
Observer HAL peak	5.1	1–10 (1.7)	5.1 (1.7)	5.3 (1.7)	0.54
Tabulated HAL peak	4.2	1–7 (1.8)	4.2 (1.8)	4.6 (1.8)	0.21
Vibration % yes	35.7	0–100 (48.0)	34.6 (47.6)	48.3 (50.9)	0.14
Wrist posture avg, % ROM†	18.8	2.4–50.3 (6.9)	18.8 (7.0)	19.4 (6.2)	0.67
Wrist posture peak % ROM†	75.3	10.0–100 (20.8)	75.5 (20.9)	73.4 (18.8)	0.61
Wrist flex/extend avg % ROM†	19.7	2.1–55.1 (7.3)	19.6 (7.2)	20.7 (8.7)	0.46

	Mean or number (%)				
	All n=347	**Range (SD)**	**CTS non-cases n=318**	**CTS cases n=29**	**p Value (χ^2 or t test)**
Wrist flex/extend peak % ROM[†]	59.6	5.3–100 (20.7)	59.5 (20.8)	60.7 (19.9)	0.76
Wrist deviation avg % ROM[†]	17.7	0–57.8 (9.7)	17.8 (9.6)	17.5 (10.2)	0.87
Wrist deviation peak % ROM[†]	70.1	1–100 (22.7)	70.4 (22.8)	66.1 (22.0)	0.33
job strain					<0.01
Low/passive/active	234 (67.4)		221 (69.5)	13 (44.8)	
High	98 (28.2)		86 (27.0)	12 (41.4)	
Missing	15 (4.3)		11 (3.5)	4 (13.8)	

[*] 6 had missing values for these variables.

[†] 8 had missing values for these variables. Exposure variables represent the average or peak of measurements across data collection visits. Wrist posture includes both flexion/extension and radial/ulnar deviation, calculated as % of full range of motion of all sampled video frames for a task, weighted by % time in task for multitask jobs. ACGIH TLV, AL is based on ACGIH TLV for HAL and TLR on Drinkaus 2005; HAL, hand activity level. Job strain, psychological demand vs decision latitude as defined by Karasek 1998.

ACGIH, American Conference for Governmental Industrial Hygienists; AL, action limit; CTS, carpal tunnel syndrome; HAL, hand activity level; ROM, Range of motion; RPE, ratings of perceived exertion; TLV, Threshold Limit Value.

Table 3

Multivariate proportional hazards models for incident dominant hand CTS

	HR	95% confidence limits	
Model 1			
Time in forceful exertion			
(≥20%–<60%) vs <20%	2.83	1.18	6.79
>60% vs <20%	19.57	5.96	64.24
BMI≥30 vs <30 kg/m^2	3.19	1.28	7.98
Model 2			
Threshold limit ratio per unit increase	1.40	1.11	1.78
BMI≥30 vs <30 kg/m^2	3.26	1.45	7.31
Job strain*			
High vs low/active/passive	2.13	1.00	4.54

Job strain, psychological demand versus decision latitude as defined by Karasek's Job Content Questionnaire.

Threshold limit ratio, Force/(7.78–0.78×HAL) based on American Conference for Governmental Industrial Hygienists Threshold Limit Value for HAL and Drinkaus 2005.

Age, gender and other potential covariates did not meet p<0.05 criteria for inclusion in the model.

*15 participants had missing values for the job strain variables due to not completing the questionnaire.

BMI, body mass index; CTS, carpal tunnel syndrome; HAL, hand activity level.