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Associations Between Workplace Factors and Carpal Tunnel Syndrome: A Multi-Site Cross Sectional Study

Z. Joyce Fan, PhD,[1] Carisa Harris-Adamson, PhD, PT,[2,3] Fred Gerr, MD,[4] Ellen A. Eisen, ScD,[2] Kurt T. Hegmann, MD,[5] Stephen Bao, PhD,[6] Barbara Silverstein, PhD,[6] Bradley Evanoff, MD,[7] Ann Marie Dale, PhD,[7] Matthew S. Thiese, PhD,[5] Arun Garg, PhD,[8] Jay Kapellusch, PhD,[8] Susan Burt, ScD,[9] Linda Merlino, MS,[4] and David Rempel, MD[10]*

Background *Few large epidemiologic studies have used rigorous case criteria, individual-level exposure measurements, and appropriate control for confounders to examine associations between workplace psychosocial and biomechanical factors and carpal tunnel syndrome (CTS).*
Methods *Pooling data from five independent research studies, we assessed associations between prevalent CTS and personal, work psychosocial, and biomechanical factors while adjusting for confounders using multivariable logistic regression.*
Results *Prevalent CTS was associated with personal factors of older age, obesity, female sex, medical conditions, previous distal upper extremity disorders, workplace measures of peak forceful hand activity, a composite measure of force and repetition (ACGIH Threshold Limit Value for Hand Activity Level), and hand vibration.*
Conclusions *In this cross-sectional analysis of production and service workers, CTS prevalence was associated with workplace and biomechanical factors. The findings were similar to those from a prospective analysis of the same cohort with differences that may be due to recall bias and other factors.* Am. J. Ind. Med. 58:509–518, 2015.

KEY WORDS: musculoskeletal disorders; physical work-load; workers; individual-level assessment; confounders

[1]Washington Traffic Safety Commission, Olympia, Washington
[2]Department of Environmental Health Sciences, University of California Berkeley, Berkeley, California
[3]Department of Physical Therapy, Samuel Merritt University, Oakland, California
[4]Department of Occupational and Environmental Health, College of Public Health, University of Iowa, Iowa City, Iowa
[5]Rocky Mountain Center for Occupational and Environmental Health (RMCOEH), University of Utah, Salt Lake City, Utah
[6]Safety and Health Assessment and Research for Prevention (SHARP) Program, Washington State Department of Labor and Industries, Olympia, Washington
[7]Division of General Medical Science, Washington University School of Medicine, Saint Louis, Missouri
[8]Center for Ergonomics, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin
[9]National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio
[10]Division of Occupational and Environmental Medicine, University of California at San Francisco, San Francisco, California
*Correspondence to: David Rempel, MD, MPH, Division of Occupational and Environmental Medicine, University of California, San Francisco 1301 S 46th Street, Building 163 Richmond, CA 94804 510-665-3403. E-mail: David.Rempel@ucsf.edu

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INTRODUCTION

Carpal tunnel syndrome (CTS) is characterized by numbness, tingling, burning, or pain in the thumb, index, and long fingers of the hand with slowing of median nerve conduction at the wrist due to entrapment of the median nerve in the carpal tunnel [Moore, 1992; Stevens, 1997]. CTS cases related to occupational exposures result in a substantial burden of worker's compensation claims, lost work time and productivity, and disability [Manktelow et al., 2004; Foley et al., 2007; Silverstein and Adams, 2007]. Due to differences in populations studied, risk factors examined, study design, and CTS case definition, there are wide ranges in the reported prevalence and incidence of electrophysiologically-confirmed CTS [Rempel et al., 1998; Silverstein et al., 2010; Descatha et al., 2011]. The prevalence of CTS in working populations ranges from 1.7% to 21% [Dale et al., 2013; Gorsche et al., 1999; Roquelaure et al., 2001; Armstrong et al., 2008; Maghsoudipour et al., 2008] and is generally higher than the rates of 1% to 4.9% observed in the general population [Stevens et al., 1988; Atroshi et al., 1999; de Krom et al., 1992; Tanaka et al., 1994]. Similarly, the incidence of CTS in workers (0.23–11 per 100 person-years) [Gorsche et al., 1999; Silverstein and Adams, 2007; Roquelaure et al., 2008a,b; Bonfiglioli et al., 2013] is higher than that in the general population (0.18–0.28 per 100 person-years) [Mondelli et al., 2002; Bongers et al., 2007].

Prior studies have reported risk factors for CTS that include personal, psychosocial, and job biomechanical exposures. Personal factors include older age [Stevens et al., 1988; Atroshi et al., 1999], female gender [Tanaka et al., 1994; Solomon et al., 1999; Geoghegan et al., 2004; Shiri et al., 2007; Silverstein and Adams, 2007], obesity [Boz et al., 2004; Geoghegan et al., 2004], diabetes mellitus [Geoghegan et al., 2004], thyroid disease [Roquer and Cano, 1993; Tanaka et al., 1994], inflammatory arthritis [Geoghegan et al., 2004; Solomon et al., 1999], and pregnancy [Zyluk, 2013]. A few studies have assessed the role of occupational psychosocial factors, reporting associations between incident CTS and high job demand, high job strain, and psychosocial distress [Roquelaure et al., 2001; Silverstein et al., 2010]. CTS has also been associated with high hand force (forceful pinch or power grip) often in combination with high repetition, and hand-arm vibration [Werner, 2006; Shiri et al., 2009; Silverstein et al., 2009; Silverstein et al., 2010; Bonfiglioli et al., 2013; Burt et al., 2013]. Many of these studies are cross-sectional in design and include non-specific case criteria based on hand symptoms alone, potentially influenced by reporting bias.

Some studies of CTS risk factors have been criticized for use of imprecise or unreliable exposure measures (e.g., job title), small sample size, retrospective methods, inadequate control of confounders, and samples that were not representative of workers and industries [Frost et al., 1998; Gell et al., 2005; Hegmann and Oostema, 2008; Roquelaure et al., 2008a,b]. To date, few large epidemiologic studies have used rigorous case criteria, individual-level biomechanical exposure measurements, and appropriate control of confounding by personal and psychosocial factors when exploring associations between biomechanical factors and risk of CTS [Violante et al., 2007; Bonfiglioli et al., 2013].

The current manuscript presents the results from a cross-sectional analysis of baseline data combined from five prospective studies of upper extremity disorders among US production and service workers. Here we assessed the associations between prevalent CTS and baseline personal and workplace psychosocial and biomechanical factors. The findings of the longitudinal analyses of the same cohort are presented in other papers (Harris-Adamson et al., 2013; Harris-Adamson et al., 2015; Kapellusch et. al., 2014). The value of conducting a cross-sectional analysis of the same cohort is that it includes prevalent CTS cases at baseline that were excluded from the prospective analysis and allows for an exploration of the differences in risk estimates between incident and prevalent CTS.

METHODS

Study Design and Participants

As part of a consortium of National Institute of Occupational Safety and Health (NIOSH)-funded studies of risk factors for upper extremity musculoskeletal disorders in industry, baseline data, collected during 2001–2004, were pooled from five independent prospective epidemiological studies conducted at 50 US companies with workers employed in production, agriculture, construction, and service sectors. Each of the five data sets included a uniform CTS case definition for dominant-hand, personal and psychosocial factors, and individual-level measurements of job biomechanical exposure. Details on the study designs, the process of pooling data, and baseline CTS prevalence are provided elsewhere [Dale et al., 2013 (site F did not include exposure data and could not be included in the analysis); Harris-Adamson et al., 2013]. Briefly, in all five studies, similar questionnaires were administered to participants at study enrollment to collect information on work history, demographics, medical history, musculoskeletal symptoms, and psychosocial work environment. In addition, electrodiagnostic studies of the median and ulnar nerves at the wrist were collected at baseline by clinicians blinded to exposure status [Harris-Adamson et al., 2013]. Each study site completed their Institutional Review Board (IRB) approval and assured that all study participants had signed a written informed consent form.

Of the 3,214 participants pooled from the five studies we excluded 55 persons who met electrophysiological criteria for possible polyneuropathy [Dale et al., 2013]. Of the remaining 3,159 subjects, 178 were missing demographic or exposure data and were excluded, leaving 2,981 participants for analysis (participation rate 94%).

Study Outcome

The study outcome was CTS in the dominant hand at the time of enrollment. The CTS case definition required: (i) dominant hand symptoms that met study criteria (described below); and (ii) electrodiagnostic study results consistent with median nerve mono-neuropathy at the wrist [Gerr and Letz, 1998; Rempel et al., 1998]. The symptom criteria were numbness, tingling, burning, and/or pain in the thumb, index finger or long finger. Median nerve mono-neuropathy was defined as temperature adjusted: (i) peak median sensory latency >3.7 ms or onset median sensory latency >3.2 ms at 14 cm; (ii) motor latency >4.5 ms; or (3) transcarpal sensory difference of >0.8 ms (the difference in sensory latencies between the median and ulnar nerves across the wrist). If a latency value was unobtainable subjects were also considered to have mono-neuropathy [Dale et al., 2013]. Workers with prior CTS surgery on the dominant hand were also included as baseline cases (N = 32).

Biomechanical Exposure Factors

Details on the collection of workplace biomechanical exposure measures from each site as well as methods used for pooling biomechanical exposure data are reported elsewhere [Kapellusch et al., 2013]. Briefly, all sites collected dominant hand force, repetition, posture, and vibration data for every individual at the task level [Silverstein et al., 1987; Chiang et al., 1993; Fung et al., 2007; Maghsoudipour et al., 2008; Garg et al., 2012]. Hand force ratings (Borg CR-10 scale, CR = category ratio, Borg 1982) were assessed by both workers and analysts. Duty cycle was quantified for all hand exertions and for forceful hand exertions alone, from videotape analysis. Forceful hand exertion was defined as ≥10 N pinch force or ≥45 N of grip force. Force was measured directly when possible or estimated using force matching or measured weights of handled tools or parts. Repetition was assessed by trained analysts using the ACGIH Hand Activity Level (HAL) rating scale (ACGIH, 2014). The HAL rating is a 10 point scale with six verbal anchors ranging from "hand idle most of the time, no regular exertions" to "rapid, steady motion/difficulty keeping up or continuous exertion." The composite ACGIH Threshold Limit Value (TLV) for HAL index was calculated using the analyst's peak force rating and analyst HAL rating. This index has a range from 0 to 1 with larger value indicating a higher risk for an upper extremity musculoskeletal disorder. Posture was quantified from the analysis of the videotapes of participants doing their job tasks as the percent time spent in >30° wrist extension and the percent time spent in >30° wrist flexion. The presence of hand/arm vibration (yes/no) was recorded by the analyst if there was visible hand/arm vibration or use of vibratory hand tools; this information was collected by four of the five sites. The 11 biomechanical exposure variables evaluated were percent time (duty cycle) in forceful hand exertion (video analysis), percent time in all hand exertions (video analysis), force ratings by worker, force ratings by analyst, repetition rate of forceful hand exertions (video analysis), repetition rate of all hand exertions (video analysis), analyst HAL rating, percent time in wrist extension, percent time in wrist flexion, vibration, and the composite ACGIH TLV for HAL index (analyst).

Most workers performed just one task but some performed two or more tasks. For workers whose job involved more than one task, task level exposures were combined to produce a job level exposure. For these workers, exposure at the job level was assessed by combining task level data using three different summary measures: (i) peak exposure (e.g., highest force, highest frequency of exertion, worst posture); (ii) typical exposure (i.e., exposure from the task performed most of the time); and (iii) time-weighted average (TWA) exposure across all tasks. The TWA approach involved weighting the exposure for each task based on the percent time the task was performed during the week. The task hours per week were estimated by the worker and supervisor. There were high correlations between job level exposure summary measures (e.g., peak, typical, and time-weighted average), with Spearman correlation coefficients ranging from 0.85 to 0.97; therefore, just the time-weighted average measure was used for subsequent analyses.

Personal and Psychosocial Factors

Information about age, gender, body mass index (BMI), race/ethnicity, education, smoking status, hand dominance, general health, physician diagnosed previous distal upper extremity disorder (e.g., wrist tendonitis, epicondylitis), and other medical conditions such as rheumatoid arthritis, diabetes mellitus, thyroid disease, and pregnancy status was collected by questionnaire at baseline from all study participants. The total number of hours spent per week in recreational hand intensive and aerobic activities, the self-reported years worked at the current employer at enrollment, whether or not the participants had received job training, and work shift (day, swing, night, or rotating) were also collected. The occupational psychosocial factors assessed were co-worker or supervisor support, job demand, decision latitude, physical or mental exhaustion after work, and job satisfaction [Bigos et al., 1991; Karasek et al., 1998]. Of these psychosocial factors, data on co-worker or supervisor support were available from three sites and the other psychosocial variables were available from four research sites. Therefore, the sample sizes for these analyses are less than for the other analyses.

Statistical Analysis

Multivariable logistic regression models were used to estimate associations between each of the 11 biomechanical exposure variables and prevalent CTS while adjusting for age, gender, obesity, medical conditions, and research site. For each model, the biomechanical exposure variables (measures of force, repetition, duty cycle, and posture) were converted to categorical values using cut points by tertiles based on the distribution in the pooled study population. The composite ACGIH TLV for HAL index scores were categorized into three levels by the Action Limit (0.56) and TLV (0.78). It is recommended that jobs with TLV for HAL scores above the Action Limit be controlled or monitored and that workers not work in jobs above the TLV (ACGIH, 2014). In addition to the crude odds ratio estimates, each of the exposure variables was further investigated by adjusting for the exposure variables from other non-overlapping domains (force, repetition, duty cycle and posture) with the least amount of missing data. Potential confounding by personal and psychosocial factors was evaluated empirically. Similar multivariable logistic regression models were conducted for the other workplace factors and recreational activity.

Potential covariates associated with the outcome ($P \leq 0.20$), that were not thought to be on the pathway from exposure to response, and had less than 10% missing data, were initially included in each multivariable model. Covariates that changed the effect estimate of the primary exposure by more than 10% were retained in the final models. Because previous distal upper extremity disorders are: (i) expected to be associated with the same exposures as CTS; and (ii) are not believed to be an independent risk factor for CTS, this variable was not initially included as a confounder for these analyses. Post-hoc analyses, i.e., analyses that deviated from this planned approach, were performed to explore unexpected findings. All analyses were conducted using SAS (v9.3) statistical software (SAS, Cary, NC).

TABLE I. Demographics and Personal Factors (N = 2,981)

	N	CTS cases	OR	(95% CI)
Age (years)				
50+	709	90	3.07	(1.97–4.79)
35–50	1,675	170	2.38	(1.57–3.62)
<35	597	27	1.00	
Gender				
Female	1,572	191	1.89	(1.46–2.44)
Male	1,409	96	1.00	
Race/ethnicity				
Hispanic	579	45	0.77	(0.55–1.10)
African American	231	28	1.27	(0.83–1.95)
Asian	164	9	0.53	(0.27–1.07)
Other	88	11	1.31	(0.68–2.52)
Caucasian	1,549	152	1.00	
Education				
Some high school or less	566	43	0.74	(0.53–1.04)
High school graduate or above	2,381	237	1.00	
Dominant hand				
Right	2,733	263	0.96	(0.61–1.50)
Left	248	24	1.00	
Obese (BMI ≥ 30)				
Yes	1,058	154	2.29	(1.79–2.93)
No	1 906	132	1.00	
General health				
Fair or poor	342	42	1.21	(0.83–1.77)
Good	1,059	118	1.08	(0.82–1.43)
Excellent or very good	1,051	109	1.00	
Medical conditions*				
Yes	362	59	2.04	(1.49–2.78)
No	2,614	228	1.00	
Previous distal upper extremity disorder				
Yes	335	76	3.48	(2.56–4.73)
No	1,877	146	1.00	
Smoking status				
Current	787	74	1.10	(0.82–1.48)
Previous	573	71	1.50	(1.11–2.03)
Never	1,601	138	1.00	

OR, Unadjusted odds ratio (OR).
*Diabetes mellitus, rheumatoid arthritis, thyroid disease, or pregnancy. Sample size may differ between variables because not all research sites collected each variable.

RESULTS

Of the 2,981 participants, 9.6% (N = 287) met the criteria for CTS at baseline. Of these prevalent CTS cases, 32 (11.1%) had been previously diagnosed by a physician as having CTS (data not shown). Compared to the non-cases, CTS cases were older (>35 years-old), more likely to be female, obese, have other medical conditions (diabetes mellitus, rheumatoid arthritis, thyroid disease, and pregnancy), report previous distal upper extremity disorders, and be past smokers (Table I). There were no statistically significant differences between the CTS cases and non-cases on race/ethnicity, education, and general health status (Table I).

There was a significant association between being moderately to severely physically exhausted after work and CTS prevalence (Table II). Workers who were dissatisfied with their jobs had higher prevalence of CTS than those who were very satisfied (OR 1.56; 95% CI 1.09–2.24). Job demand, decision latitude, supervisor or co-worker support,

TABLE II. Multivariable Analyses of Recreation and Workplace Factors*

	N	CTS cases	OR	(95% CI)
Recreational hand intensive activity				
>3 hr/week	1,590	165	1.63	(1.17–2.27)
<=3 hr/week	812	54	1.00	
Recreational aerobic activity				
>3 hr/week	626	89	1.40	(1.01–1.95)
<=3 hr/week	1,126	84	1.00	
Workplace factors				
Years worked at enrollment				
<=1	389	33	1.15	(0.75–1.76)
1 to <=7	1,269	114	0.91	(0.69–1.20)
>7	1 297	133	1.00	
Job demand				
High	917	71	1.11	(0.77–1.60)
Low	906	63	1.00	
Decision latitude				
Low	810	61	1.31	(0.91–1.88)
High	1,062	74	1.00	
Supervisor or co-worker support				
Low	410	17	0.93	(0.44–1.96)
High	351	14	1.00	
Physically exhausted after work				
Moderate to severely exhausted	961	137	1.64	(1.26–2.13)
None to slightly exhausted	1,580	135	1.00	
Mentally exhausted after work				
Moderate to severely exhausted	682	84	1.20	(0.91–1.60)
None to slightly exhausted	1,875	194	1.00	
Job satisfaction				
Poorly satisfied	420	60	1.56	(1.09–2.25)
Satisfied	1,349	129	0.95	(0.71–1.27)
Very satisfied	827	85	1.00	
Receiving job training				
None to little	291	29	1.22	(0.78–1.89)
Some to a lot	1,224	103	1.00	
Work shift				
Day	2,467	257	1.79	(0.77–4.17)
Swing	311	19	1.51	(0.58–3.93)
Rotating or night	118	6	1.00	

CTS, Carpal tunnel syndrome; CI, Confidence interval.
*Odds ratios (OR) adjusted for age, gender, obesity, medical conditions, and research sites. Each risk factor was examined in a separate model. Sample size may differ between variables because not all research sites collected each variable.

feeling mentally exhausted after work, job tenure, work shift, and job training were not significantly related to CTS prevalence.

Six job biomechanical exposure measures had significant associations with CTS after adjusting for age, gender, obesity, medical conditions, and research site: percent time in forceful hand exertions (duty cycle), worker rated hand exertion (Borg CR-10), analyst rated hand exertion (Borg CR-10), forceful repetition rate, composite ACGIH TLV for HAL index, and working with vibrating tools (Table III). In contrast, total percent time in all hand exertion (duty cycle), total hand repetition rate, analyst's HAL rating (repetition), wrist extension $\geq 30°$, and wrist flexion $\geq 30°$ were not significantly related to CTS prevalence. These findings were unchanged after adjusting the models for biomechanical exposures from the other domains.

Given the association observed between previous distal upper extremity disorder and CTS a post-hoc analysis of the

TABLE III. Multivariable Analyses on Biomechanical Exposures at Job Level

	Adjusted for non-exposure factors[a]				Adjusted also for exposure variables from other domains			
	Cohort (N)	CTS cases	OR	(95% CI)	Cohort (N)	CTS cases	OR	(95% CI)
Duty cycle								
Forceful hand exertions, % time (video analysis)								
>32	2,815	85	1.50	(1.06–2.12)	2,699[b]	80	1.36	(0.93–1.99)
>11 to ≤32		111	1.69	(1.23–2.32)		108	1.60	(1.14–2.25)
≤11		82	1.00			81	1.00	
All hand exertions, % time (video analysis)								
>76	2,539	94	0.91	(0.66–1.26)	2,426[b]	92	0.91	(0.65–1.27)
>60 to ≤76		92	1.08	(0.78–1.48)		86	0.98	(0.71–1.36)
≤60		92	1.00			91	1.00	
Force								
Worker rating (Borg CR-10)								
>4	2,507	112	2.04	(1.45–2.88)	2,255[c]	108	2.05	(1.42–2.87)
>2.5 to ≤4		88	1.23	(0.86–1.75)		87	1.24	(0.86–1.78)
≤2.5		65	1.00			61	1.00	
Analyst rating (Borg CR-10)								
>4	2,853	88	1.32	(0.96–1.82)	2,426[c]	85	1.32	(0.95–1.84)
>2.5 to ≤4		88	1.42	(1.04–1.96)		88	1.44	(1.04–2.00)
≤2.5		102	1.00			96	1.00	
Repetition								
Repetition of forceful hand exertions, per min (video)								
>10	2,815	110	1.45	(1.03–2.04)	2,774[d]	108	1.45	(1.03–2.04)
>3 to ≤10		90	1.21	(0.89–1.64)		90	1.22	(0.90–1.66)
≤3		78	1.00			78	1.00	
Repetition of all hand exertions, per min (video)								
>25	2,539	100	1.33	(0.93–1.91)	2,426[b]	93	1.32	(0.92–1.90)
>13 to ≤25		95	1.13	(0.82–1.57)		94	1.11	(0.80–1.90)
≤13		83	1.00			82	1.00	
Analyst HAL rating								
>6	2,869	62	1.33	(0.96–1.82)	2,438[b]	60	1.32	(0.95–1.83)
>4 to ≤6		119	1.12	(0.80–1.57)		104	1.10	(0.78–1.55)
≤4		98	1.00			92	1.00	
Posture								
Wrist extension ≥30°, % time (video analysis)								
>14	2,801	99	1.03	(0.71–1.48)	2,426[e]	95	1.07	(0.74–1.55)
>1.5 to ≤14		87	1.30	(0.91–1.86)		84	1.27	(0.89–1.82)
≤1.5		91	1.00			90	1.00	
Wrist flexion ≥30°, % time (video analysis)								
>3	2,802	80	1.09	(0.8–1.49)	2,426[e]	79	1.03	(0.75–1.54)
>0 to ≤3		75	1.25	(0.9–1.74)		72	1.24	(0.89–1.74)
=0		122	1.00			118	1.00	
Vibration (analyst assessment)								
Yes	2,524	127	1.71	(1.28–2.29)	2,018[f]	108	1.57	(1.13–2.18)
No		131	1.00			126	1.00	
Composite index								
HAL-TLV (analyst HAL and force rating)								
>0.78	2,816	90	1.74	(1.27–2.39)	2,662[d]	89	1.40	(1.03–1.91)
>0.56 to ≤0.78		64	1.36	(0.91–2.02)		63	1.54	(1.09–2.16)
≤0.56		119	1.00			113	1.00	

[a] All models included age, gender, obesity, medical conditions, and research sites. Each time weighted average exposure variables was examined in a separate model. Sample size may differ between variables because not all research sites collected each variable. CTS, Carpal tunnel syndrome; CI, Confidence interval; HAL, Hand activity level; TLV, Threshold limit value.

[b] Adjusted for analyst rating force, % time ≥30° wrist extension.

[c] Adjusted for total repetition, % duration all exertions, % time ≥30° wrist flexion.

[d] Adjusted for % time ≥30° wrist extension.

[e] Adjusted for analyst rating force, total repetition, % duration all exertions.

[f] Adjusted for analyst rating force, total repetition, % duration all exertions, % time ≥30° wrist extension.

subset of subjects with previous distal upper extremity disorder data was conducted for all models with previous distal upper extremity disorder entered as a covariate. For the models in Table II, the effect estimates remained relatively unchanged (<10% difference) except for the effect of high job demand (OR = 1.54; 95%CI: 0.94–2.53) which was enhanced, and the effect of more than 3 hr per week of recreational aerobic activity (OR = 1.1; 95%CI: 0.77–1.58), and more than 3 hr per week recreational hand intensive activity (OR = 1.19; 95%CI: 0.82–1.72) per week, which were attenuated with this adjustment. When previous distal upper extremity disorder was added to the biomechanical models in Table III, the sample size was reduced, but effect estimates remained within 10% of those reported with the exception of the effects of spending between 11 to 32% time in forceful hand exertion (OR = 1.23; 95%CI: 0.83–1.81) and forceful repetition rate greater than 10 exertions per minute (OR = 1.27; 95%CI: 0.87–1.87) which were significantly attenuated. Effect estimates for total repetition rate and the analyst HAL rating were also attenuated toward the null by more than 10% and remained statistically non-significant.

DISCUSSION

Jobs requiring forceful hand exertions were associated with prevalent CTS in this cross-sectional, multisite study. Specifically, multiple metrics of forceful hand activities, i.e., duty cycle, worker or analyst ratings, and repetition rate of forceful exertions, were observed to be consistently and strongly associated with prevalent CTS after adjusting for covariates. Alternatively, total hand repetition rate and wrist posture were not associated with prevalent CTS. The ACGIH TLV© for HAL composite index, a metric that combines force and repetition, was also associated with CTS. Older age, obesity, female gender, reporting of another medical condition (diabetes mellitus, rheumatoid arthritis, thyroid disease, or pregnancy), or a prior distal upper extremity disorder, and engaging in recreational hand activities were also associated with prevalent CTS.

The observed association between elevated hand force and CTS prevalence is consistent with previous studies. Forceful gripping of greater than 10 N was associated with CTS in a case-control study [Roquelaure et al., 1997] and a cross sectional study [Maghsoudipour et al., 2008] and sustained forceful movement of the wrist was a risk factor for CTS in a case-control study [Fung et al., 2007]. Peak hand force was also found to predict risk of CTS in two prospective studies [Werner et al., 2005; Bonfiglioli et al., 2013] and the longitudinal analysis from our pooled dataset [Harris-Adamson et al., 2015].

Measures of hand repetition have been associated with CTS in some prior studies [Silverstein et al., 1986; Chiang et al., 1990; Roquelaure et al., 2001; Bonfiglioli et al., 2006; Maghsoudipour et al., 2008; Bonfiglioli et al., 2013] but not others [McCormack et al., 1990; Moore and Garg, 1994; Nathan et al., 2005]. We found no association between CTS and measures of total hand repetition based on either video analysis or analyst estimates of repetition using the HAL scale. In contrast, CTS was related to hand repetition when repetition rate included forceful hand exertions alone (e.g., ≥10 N pinch force or ≥45 N grip force). These findings are consistent with the longitudinal analysis of our cohort [Harris-Adamson et al., 2015]. In most prior studies reporting an association between repetition and CTS, the investigators did not specify whether a minimum level of hand force was required for a hand exertion to be counted as a repetition. Likewise, the positive association of the composite ACGIH TLV for HAL in the current study appears primarily to be due to the contribution from the peak force rating, not the HAL scale rating for repetition. Again, this finding is consistent with the longitudinal analysis of the same cohort [Kapellusch et. al., 2014]. Overall, these results suggest that the metrics of repetition commonly used in occupational epidemiological studies may not be important risk factor for CTS or that the variation in or magnitude of repetition in the cohorts studied were insufficient for an association to be observed.

A significant association between use of vibrating tools and prevalent CTS was observed after adjusting for analyst rating of hand force, repetition, age, gender, obesity, medical conditions, and research sites. No such association was observed in the longitudinal analysis of the same cohort [Harris-Adamson et al., 2015]. Exposure assessment in both studies was based on analyst observations; therefore, the differences are not explained by a reporting bias. It may be that the effects of vibration take longer to manifest than the follow-up period of the longitudinal analysis. The finding that hand vibration was associated with CTS, independent of the application of high hand forces, is compatible with prior studies of quarry/rock drillers, stonemasons, and forestry workers exposed to hand-arm vibration [Bovenzi, 1994; Farkkila et al., 1988; Barcenilla et al., 2012].

In our study, percent time in wrist extension or flexion was not associated with CTS prevalence. However, the mean percent time that subjects were in wrist flexion during work was low (<3% time). A number of prior studies of CTS that measured wrist posture also failed to observe associations between posture and CTS [Silverstein et al., 1986; Silverstein et al., 1987; Moore and Garg, 1994; Roquelaure et al., 1997; Nordstrom et al., 1998]. However, some cross-sectional and case-control studies have identified posture, such as bending or twisting of the hands or wrists over 30 degrees [Maghsoudipour et al., 2008] or frequent flexion or extension [de Krom et al., 1990; Fung et al., 2007], as CTS risk factors.

CTS prevalence was greater among workers who reported spending more than 3 hr/week on recreational hand intensive or aerobic activities than among those who spent less than 3 hr/week on these activities (Table II). The direction of effect (i.e., participants who reported engaging in these activities were at increased risk of prevalent CTS) is opposite to the direction of the effect of these activities on incident CTS cases in the longitudinal analysis (i.e., participants who reported engaging in these activities were at lower or no increased risk of incident CTS) [Harris et al., 2013]. This discrepancy is consistent with biased recall of these activities among participants with symptoms of CTS at the time of the baseline survey. Previous physician diagnosed distal upper extremity disorders, such as wrist tendonitis, were also associated with prevalent CTS in the current study. The personal factors observed to be associated with CTS, e.g., age, obesity, female sex, and other medical conditions add to a large body of prior evidence of association [Franklin et al., 1991; Nordstrom et al., 1997; Atroshi et al., 1999; Solomon et al., 1999; Boz et al., 2004; Geoghegan et al., 2004; Shiri et al., 2007].

Because of potential estimation problems, our original analytical strategy did not include adjustment of associations between CTS risk factors and prevalent CTS by the variable previous distal upper extremity disorder. After post-hoc adjustment for previous distal upper extremity disorder, the positive association between recreational hand intensive or aerobic activities and prevalent CTS was eliminated. Post-hoc adjustments of associations between biomechanical factors and prevalent CTS by previous distal upper extremity disorder resulted in a modest reduction in the magnitude of observed odds ratios. Despite these effects on observed odds ratios, we believe that previous distal upper extremity disorder should not be considered a confounding variable in these analyses and that its inclusion in multivariate analyses leads to biased effect estimates. First, many cases of previous distal upper extremity disorder are the result of biomechanical exposures that are also etiological of CTS. Therefore, the variable previous distal upper extremity disorder acts as surrogates for these exposures and its inclusion artifactually attenuates the observed strength of association in models exploring relationships between biomechanical exposures and CTS. Second, it is also possible that those reporting a previous distal upper extremity disorder had experienced an early but undiagnosed cases of CTS (or fully-developed CTS event that was misdiagnosed as another upper extremity disorder). In this case, its inclusion would also result in attenuation of the observed association between risk factors and prevalent CTS as a consequence of over-controlling.

Relatively few studies have assessed workplace psychosocial factors as a risk for CTS and no consistent associations have been identified [Nordstrom et al., 1997; Werner et al., 1998; Leclerc et al., 2001]. In our study, high job demand and low supervisor and co-worker support were not associated to prevalent CTS; however, in the prospective analysis from the same cohort they were associated with incident CTS [Harris-Adamson et al., 2013]. Conversely, job satisfaction was associated with prevalent CTS but not with incident CTS in this cohort [Harris-Adamson et al., 2013]. These observations may be the result of cause-effect reversal bias that can affect studies collecting exposure and health information simultaneously. Specifically, it is possible that CTS symptoms resulted in lower job satisfaction rather than the alternate possibility that job satisfaction is a true risk for CTS.

Several important limitations of the current study should be noted. First, it is possible that workers with CTS onset prior to enrollment may have moved to a lower biomechanical exposure group (i.e., selective survival) thereby attenuating the strength of observed associations. This process, of course, cannot account for the positive associations that were observed between occupational biomechanical risk factors and prevalent CTS. Second, because non-occupational hand activities and job satisfaction information (among others) was collected by questionnaire, the experience of CTS symptoms may have affected participant reporting behavior. Such a bias would not be expected for the biomechanical factors (except for worker reported hand force) since exposures were estimated by analysts who were unaware of participant CTS status. Consequently, greater caution is required when interpreting information reported by participants than information that was collected by investigators who were blinded to participant health status. Also, while the intent of pooling data from multiple research sites was to increase the statistical power, some of the exposure variables (e.g., vibration and psychosocial data) were not collected by all sites, leading to differences in sample sizes and power. Lastly, not all sites collected information on non-participants; therefore, we cannot know if those who chose not to participate were different in exposure or personal factors than those who did.

CONCLUSION

In this large multi-site cross-sectional study, we found that jobs requiring high hand force were associated with an increased CTS prevalence after adjusting for important confounders. Similar to findings from the incident analysis of the same cohort, hand force was consistently observed to be strongly associated with the prevalence of CTS, while repetition on its own and wrist posture were not. This supports the conclusion that for jobs at high risk for CTS, an injury prevention strategy should include reducing forceful hand exertion intensity and duration.

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