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Self-reported physical work exposures and incident carpal tunnel syndrome

Ann Marie Dale, PhD, OTR/L[1], **Bethany T. Gardner, OTD, OTR/L**[1], **Angelique Zeringue, MS**[1,2], **Jaime Strickland, MA**[1], **Alexis Descatha, MD**[3], **Alfred Franzblau, MD**[4], and **Bradley Evanoff, MD, MPH**[1]

[1]Division of General Medical Sciences, Washington University School of Medicine, St. Louis, MO, USA

[2]Department of Biostatistics, School of Public Health, St. Louis University, St. Louis, MO, USA

[3]Inserm U1018- AP-HP, Occupational Health Unit, F92380, Garches, France

[4]Department of Environmental Health Sciences, University of Michigan School of Public Health, Ann Arbor, MI, USA

Abstract

Background—To prospectively evaluate associations between self-reported physical work exposures and incident carpal tunnel syndrome (CTS).

Methods—Newly employed workers (n=1,107) underwent repeated nerve conduction studies (NCS), and periodic surveys on hand symptoms and physical work exposures including average daily duration of wrist bending, forearm rotation, finger pinching, using vibrating tools, finger/thumb pressing, forceful gripping, and lifting >2 pounds. Multiple logistic regression models examined relationships between *peak*, *most recent*, and *time-weighted average exposures* and incident CTS, adjusting for age, gender, and body mass index.

Results—710 subjects (64.1%) completed follow-up NCS; 31 incident cases of CTS occurred over 3 year follow-up. All models describing lifting or forceful gripping exposures predicted future CTS. Vibrating tool use was predictive in some models.

Conclusions—Self-reported exposures showed consistent risks across different exposure models in this prospective study. Workers' self-reported job demands can provide useful information for targeting work interventions.

Keywords

carpal tunnel syndrome; physical work exposures; self-report; occupational health; prospective; longitudinal studies

Corresponding author: Ann Marie Dale, Division of General Medical Sciences, Campus Box 8005, Washington University School of Medicine, 660 S. Euclid Ave., St. Louis, MO 63110. adale@dom.wustl.edu. Phone: 314-454-8470; Fax: 314-454-5113.

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INTRODUCTION

Carpal tunnel syndrome (CTS) is a common and painful hand disorder that occurs more frequently among workers in occupations with high physical exposures [Roquelaure et al., 2009]. CTS is one of the most costly occupational injuries for employers and is also quite disabling for the injured worker [Bureau of Labor Statistics (BLS), 2013; Foley et al., 2007]. Physical work exposures associated with increased risk of CTS include forceful and repetitive hand movements and use of vibrating tools [Barcenilla et al., 2012; Bernard, 1997; Burt et al., 2011; Roquelaure et al., 2009; Shiri et al., 2009]. Personal risk factors also associated with CTS include age, gender, body mass index (BMI), pregnancy, and comorbid medical conditions including diabetes and rheumatoid arthritis [Armstrong et al., 2008; Atcheson et al., 1998; Burt et al., 2011; Geoghegan et al., 2004; Stevens et al., 1992].

Methods for assessing physical work exposures of the upper extremities vary widely and have included worker self-report, job observation, and direct measurement. All of these methods have inherent strengths and limitations. Observation and direct measurement are expensive and time consuming to collect and may lead to exposure misclassification by not accounting for all variation in exposure between workers or within multi-task jobs during limited periods of observation [Burdorf, 1993; Hansson et al., 2001; Mathiassen and Paquet, 2010]. Self-reported exposures from questionnaires provide individual level data and are relatively simple and inexpensive to administer to large working populations compared to observation or direct measurement, but are generally considered to be less accurate [Spielholz et al., 2001; van der Beek and Frings-Dresen, 1998; Viikari-Juntura et al., 1996].

Several studies have evaluated agreement between self-reported exposure estimates and those made by observation or direct measurement within the same cohort. These studies have had variable results. Some studies have shown differential reporting of self-reported exposures by workers with musculoskeletal symptoms or job-related psychosocial stressors, who either overestimated or underestimated their physical work exposures [Balogh et al., 2004; Buchholz et al., 2008; Hansson et al., 2001; Viikari-Juntura et al., 1996; Wiktorin et al., 1993]. Other studies have shown no systematic differences in exposure reporting related to musculoskeletal complaints [Dale et al., 2010; Ditchen et al., 2013; Toomingas et al., 1997]. Some researchers have suggested that self-reports may evaluate a different dimension of exposure and thus may be complementary to observational methods [Descatha et al., 2009]. Most studies of physical work exposures have compared agreement between different exposure methods in cross-sectional studies rather than testing how different exposure methods predict future musculoskeletal disorders in longitudinal studies. If different exposure methods capture a different dimension of exposure, different methods may contribute uniquely to predicting the outcome.

The aim of this longitudinal study was to evaluate the association between prospectively collected self-reported work exposures and incident carpal tunnel syndrome. The effects of different time patterns of exposure have not been well described in existing longitudinal exposure-response studies for CTS. Thus, we evaluated how well three different time patterns of self-reported exposure predicted future CTS, including the *peak* or maximum value of exposure, *most recent exposure*, and the *time-weighted average* exposure based on total time employed.

MATERIALS AND METHODS

Subject recruitment

Workers were recruited from eight participating employers and three construction trade unions between July 2004 and October 2006 into the prospective Predictors of Carpal Tunnel Syndrome (PrediCTS) study. Workers were predominantly employed in clerical, service, and construction (carpentry/floor laying/sheetmetal) jobs. Inclusion criteria included being at least 18 years old, English speaking, working at least 30 hours per week, and being newly hired or becoming benefits eligible within the last 30 days. Workers were excluded if they were pregnant at baseline, had a history of CTS or peripheral neuropathy, or other contraindication to receiving nerve conduction studies (NCS). This study was approved by the Institutional Review Boards of the Washington University in St. Louis School of Medicine and the University of Michigan. All subjects provided written informed consent and were compensated for their participation.

Data collection

Workers underwent physical exams and bilateral NCS of the hand at baseline and were re-tested as close to three years as was feasible for each subject. They also completed surveys of demographics, employment and medical histories, physical work exposures, and hand symptoms at 6 month, 18 month, 36 month, and 5 year follow-up. NCS were conducted by trained technicians using the NC-stat automated testing device (NEUROMetrix, Inc., Waltham, MA). All NCS values were temperature adjusted to 32 degrees Celsius based on the manufacturer's recommendations. The distal sensory latencies (DSL) and median ulnar sensory latency difference (MUDS) were also length adjusted to a standard 14 centimeter distance between stimulus and response electrodes. The NC-stat device uses conduction volume methodology to obtain the distal motor latencies (DML), so no length adjustments were necessary.

Outcome

The CTS outcome was defined as presence of specific median nerve symptoms reported on survey and median neuropathy at 3-year follow-up testing. Median nerve symptoms included numbness, tingling, burning, or pain in at least one of the thumb, index, or middle fingers. Subjects indicated the location and description of symptoms on a hand diagram with scores based on modified rules from Katz [Dale et al., 2008; Franzblau et al., 1994; Katz et al., 1990]. Diagrams were rated separately by an occupational therapist and an occupational physician (AMD, BE) for consistency with CTS symptoms; discrepancies were resolved by consensus. Criteria for median neuropathy were median DML greater than 4.5 milliseconds (ms), median DSL greater than 3.5 ms, or MUDS greater than 0.5 ms [Silverstein et al., 2010]. Absent DSL values were considered abnormal. Subjects were counted as a CTS case if they met the case definition (symptoms plus median neuropathy) for either hand.

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Physical work exposures

Physical work exposures were collected using a modified Nordstrom questionnaire [Nordstrom et al., 1998]. Exposures were reported as the average daily time spent in lifting objects weighing more than 2 pounds, using vibrating hand tools, forearm rotation, hand/wrist bending, forceful gripping, finger/thumb pushing/pressing, and finger pinching. All exposure values were dichotomized as none of the self-reported exposure values were normally distributed. We categorized all exposures as greater than 4 hours versus less, except for the finger pinching exposure, which was dichotomized at greater than 2 hours, similar to cut-points that have been used in previous exposure measures and studies [ACGIH, 2001; Herquelot et al., 2013; Latza et al., 2000; Richter et al., 2012; Silverstein et al., 1987]. We described self-reported work exposures by three different approaches in separate regression models. *Most recent exposure* was defined as the exposure reported on the questionnaire prior to the visit at which the NCS and symptoms outcomes were recorded. *Peak exposure* was defined as the highest value reported for each exposure over the study period and could have included the retest visit at which repeat NCS were performed. *Employed time-weighted average exposure* was computed as the average exposure in the jobs performed during the study period with exposures captured in surveys including the retest visit at which repeat NCS were performed, time-weighted based on the job length for each exposure. Unemployed time was excluded from the total time subjects were employed. Since subjects reported different exposures in jobs across time, we weighted each exposure by the interval between surveys. Exposures reported on jobs that had not been held for more than a year prior to any survey date were excluded from analysis.

Statistical Analysis

We computed bivariate logistic regression models of the physical exposure, demographic, and clinical variables on the CTS outcome. We then conducted multiple logistic regression models separately examining the relationship between each self-reported exposure variable after adjusting for age, body mass index (BMI), and gender. The prevalence of diabetes mellitus in the cohort was too low (n=24) to contribute meaningfully to explaining the variance in CTS, so it was not included in the final univariate or multivariate models. Self-reported exposures were examined in separate models as most were correlated to varying degrees (Spearman correlation coefficients ranged from 0.21–0.66). We calculated the Akaike information criterion (AIC) as a measure of the relative quality or goodness of fit of the models; lower values for AIC indicated better relative model fit. We examined the AIC for each exposure variable in separate models across the three different time patterns of exposure to describe which model provided the best fit for predicting incident CTS.

We also ran a sensitivity analysis to assess whether the presence of CTS symptoms, as previously described, had an effect on the reporting of exposures by subjects in the study. For the *most recent exposure* analyses, we excluded any subjects who reported CTS symptoms at the time-point prior to their *most recent exposure*. We then repeated the multivariate logistic regression analyses for the significant exposure variables using only the subset of all asymptomatic subjects. All analyses were conducted using SAS 9.3 (Cary, NC).

RESULTS

Of the 1,107 subjects recruited for the original study, 751 (67.8%) completed the follow-up physical examination and repeat NCS. Comparing subjects who completed the follow-up visit with subjects lost to follow-up showed no statistically significant differences in baseline characteristics of age, gender, body mass index (BMI), medical history, or baseline job category. At the baseline evaluation, 34 of the 751 subjects met our criteria for CTS and were excluded from the incident CTS analysis; 6 subjects had missing or incomplete data and were excluded. An additional subject was excluded for missing self-reported exposure information, leaving 710 (64.1%) for the present analysis. Subjects completed an average of 4 surveys over a mean follow-up period of 3.3 years (0.9 SD). As seen in Table I, the cohort was young (mean age: 30.6 years), predominantly male (64.4%), overweight (mean BMI: 28.2), and employed in construction (40.8%), clerical (36.9%), and service industry jobs at baseline (22.3%). Over the study period, workers completed surveys on a mean of 2.3 jobs (0.9 SD), defined by unique Standard Occupational Classification (SOC) codes. On average, the *most recent exposure* was reported on a survey which preceded the re-evaluation for CTS by 14 months. At retest, 75 (10.6%) workers reported specific median nerve symptoms described on a hand diagram in one or both hands and 163 (23.0%) had median neuropathy in one or both hands. Based on our case definition, 31 subjects developed CTS, 23 unilateral (15 dominant hand, 8 non-dominant hand) and 8 bilateral, and became incident cases.

In univariate analyses, age, BMI, lifting objects for more than 4 hours, and forceful gripping for more than 4 hours were significant risk factors for developing CTS (Table II). Table III shows the results of the multivariate analyses adjusted for age, gender, and BMI. Each exposure variable was entered separately in models due to the levels of correlation between exposures (r=0.21–0.66). Adjusting for age, gender, and BMI, self-reported lifting or carrying objects for more than 4 hours per day remained a significant predictor of CTS, regardless of whether exposure was defined based on the *most recent exposure* (OR: 2.98, 95% CI: 1.41–6.31), the *peak exposure* (OR: 3.61, 95% CI: 1.41–9.24), or the *employed-time weighted average exposure* (OR: 2.23, 95% CI: 1.05–4.73). Forceful gripping during work tasks for more than 4 hours per day was also a significant risk factor for CTS across all time patterns of exposure. Though vibrating tool use for more than 4 hours per day was not significant in univariate analyses, *peak exposure* (OR: 2.24, 95% CI: 1.02–4.92) and *employed time-weighted average exposure* (OR: 2.74 95% CI: 1.13–6.65) were significant in multivariate models controlling for personal factors. The AIC showed there was little variation in model fit between the three different time patterns of self-reported exposure. Some exposures, such as finger pinching and thumb pressing, had high AIC values across all time patterns and therefore less contribution to the model fit. *Employed time-weighted average exposures* showed better performance (lower AIC values) across all exposure variables for predicting incident CTS than the *peak* or *most recent exposures*.

In a sensitivity analysis to evaluate the effects of symptoms on reported exposures, 54 of the 710 subjects reported CTS symptoms at the time-point immediately prior to their *most recent exposure.* Of these 54 subjects, 8 subsequently became CTS cases at follow-up. When we excluded these 54 subjects with CTS symptoms prior to their reported *most recent exposures*, we found higher point estimates in multivariate regression models of exposure among the non-symptomatic group (n=656) [(Lifting objects: OR: 3.53, 95% CI: 1.47, 8.49), (Using vibrating tools: OR: 2.52, 95% CI: 0.91, 6.95), (Forceful gripping: OR: 3.24 (1.34, 7.87)] compared to models of the full cohort (n=710) as seen in Table III.

DISCUSSION

The results of this prospective study showed that self-reported work exposures to prolonged lifting, forceful gripping, and using vibrating hand tools increased the risk of future CTS after adjusting for age, gender, and BMI. Our findings showed positive associations of CTS with reported exposures across models using three separate time patterns of self-reported exposure, including the *most recent, peak, and employed time-weighted average exposures. Employed time-weighted exposures* seemed to provide the best overall model fit for predicting CTS.

Our results are consistent with recent studies that have found an increased risk for CTS due to forceful hand movements (lifting OR ranging from 2.23 to 3.61 and forceful gripping OR 2.21–2.70), and use of vibrating tools (OR 2.24–2.74) using both self-reported [Shiri et al. 2009] and observed exposures [Bonfiglioli et al. 2013; Burt et al. 2011; Burt et al. 2013; Silverstein et al. 2010] In a 2009 study by Shiri et al., self-reported work tasks with more than 2 hours of vibrating tools (adjusted OR 1.9, 95% CI: 1.2, 2.9) and more than 1 hour of forceful hand gripping (OR 1.7, 95% CI: 1.2, 2.5) were independently associated with an increased risk for CTS, but only in the most recent job as opposed to past jobs held. Using observed exposures in a cross-sectional study, Burt et al. (2011) showed that high peak force demands, defined as >70% maximum voluntary contraction (MVC), increased the risk for CTS (OR 2.74, 95% CI: 1.32, 5.68) versus jobs with peak force demands < 20% MVC. High repetition (>15 exertions per minute) was also associated with increased risk (OR 3.35, 95% CI: 1.14, 9.87), for subjects with a BMI >30. Our study found significant associations between incident CTS and exposures of force and vibration in models adjusted for personal factors, and supports the findings of these previous studies.

One of the unique features of the present study was the comparison of three different time patterns of physical work exposures that have been applied by other researchers to data collected by self-reported exposure, observation, job exposure matrices, and workplace surveillance studies. The time patterns of exposure that we chose for comparison were *peak exposure* [Bao et al., 2009; Benke et al., 2008; Burt et al., 2011], *most recent exposure* [Benke et al., 2008; Evanoff et al., 2014; Shiri et al., 2009], and *employed time-weighted average exposure* excluding unemployed time [Bao et al., 2006; Bao et al., 2009; Benke et al., 2008; Burt et al., 2011; Evanoff et al., 2014].

In a 2009 study, Bao et al. compared 6 different time patterns of exposure for calculating upper extremity exposure with the Strain Index (SI) using data collected by observational methods. Exposure patterns included the most common force, the peak force, the time-weighted average, or a composite SI approach. Despite the different time patterns of exposure yielding SI scores with different magnitudes, all approaches were highly correlated with one another. The authors concluded that although each approach should have different recommended cut-points for classifying the relative risk level of jobs, all time patterns of exposure would yield similar results for risk identification, using data from one source but profiled differently in various models [Bao et al., 2009]. Our study compared the ability of different exposure models to predict future cases of CTS, and found that all three of our time patterns of self-reported exposure identified consistent risk factors for CTS, with some variation in the point estimates. All of our exposure approaches identified lifting objects and forceful gripping as significant risks for CTS, and 2 out of 3 approaches (*most recent* and *employed time-weighted exposure*) identified use of vibrating hand tools. This consistency of risks associated with CTS across multiple approaches provides support for using self-reported exposure assessment in large epidemiological studies of musculoskeletal disorders.

Selection of appropriate exposure assessment strategies requires careful thought and logistical trade-offs. The strategy may vary depending upon the purpose of the research or application of the findings such as in examining exposure-response relationships, identifying high relative risk jobs, or recommending ergonomic interventions [Dempsey and Mathiassen, 2006; Takala et al., 2010]. Furthermore, the characteristics of the jobs to be studied influence which method is most appropriate such as how variable the tasks or demands are within a job, and whether the variance in demands is between days, individuals, or seasons [Barrero et al., 2009; Dempsey and Mathiassen, 2006; Ditchen et al., 2013; Viikari-Juntura et al., 1996; Wiktorin et al., 1993]. Furthermore, defining dose-response relationships is made more difficult for multi-task jobs with highly variable exposures, and in the case of some of the workers in our cohort, for multiple jobs each with multiple tasks over a multi-year longitudinal study follow-up.

Self-reported physical work exposures are commonly used in epidemiological studies when collection of individual level data is required on large numbers of workers. Self-reported exposures may be more feasible than observation or direct measurement methods due to the relatively low cost and ease of administration in working populations. Other benefits of using self-reported exposures include utility in assessing and integrating exposures which are highly variable over time in comparison with observed methods which are usually limited to a relatively short period of observation [Barrero et al., 2009; Ditchen et al., 2013; Viikari-Juntura et al., 1996; Wiktorin et al., 1993]. Self-reported exposures also allow for the ability to perform retrospective exposure assessment although retrospective assessment could potentially introduce additional bias to exposure estimates.

Previous studies have assessed the validity of self-reported exposures by comparison to observed or directly measured exposures with varied results ranging from poor to good agreement for individual survey items [Descatha et al., 2009; Hansson et al., 2001; Latko et al., 1997; Nordstrom et al., 1998; Pope et al., 1998; Somville et al., 2006; Spielholz et al., 2001; Stock et al., 2005; Viikari-Juntura et al., 1996], leading to the frequent conclusion that self-reports are imprecise. Barrero et al. (2009) suggested in a recent review that the often low agreement between self-reported and observed methods may be due to the methodological characteristics of previous studies, such as cross-sectional designs, small sample sizes, and comparison of exposures with different measurement scales, and not due to the true validity of self-reported measures for assessing exposure in working populations. Furthermore, past cross-sectional comparisons have only evaluated the level of agreement between different exposure methods, rather than assessing how well different exposures predict risk for future musculoskeletal disorders.

Two previous studies of musculoskeletal disorders included both cross-sectional comparisons of exposure methods and longitudinal comparisons of the exposure-response relationship in the same respective cohorts [Descatha et al., 2009; Somville et al., 2006]. Somville et al. (2006) found modest agreement between self-reported and observed estimates, but similar relative risks for incident low back pain between self-reported and observed estimates. Descatha et al. (2009) found low agreement between self-reported and observed estimates but more precise identification of incident upper extremity musculoskeletal disorders by self-reports than observation. Descatha suggested that self-reports may evaluate a different dimension of exposure and thus may be complementary to observational methods [Descatha et al., 2009]. Findings in our cohort have been similar to these two previous studies. In a previous study, we made cross-sectional comparisons between observed and self-reported exposures of the upper extremities using the same Nordstrom scale in the PrediCTS cohort and found various levels of agreement ranging from substantial to little or no agreement for different variables studied [Dale et al., 2010]. In another study, we saw similar patterns of agreement between job-title based exposure estimates and these other methods [Gardner et al., 2010]. Our present longitudinal study of the exposure-response relationship for CTS shows strong associations between self-reported exposures and incident CTS. Additional studies are needed to determine the unique contributions of different exposure methods for predicting the outcome of interest.

An often cited perceived limitation of self-reported exposures is that some previous studies have shown differential reporting of exposure by workers currently experiencing symptoms [Balogh et al., 2004; Buchholz et al., 2008; Hansson et al., 2001; Viikari-Juntura et al., 1996; Wiktorin et al., 1993]. On the contrary, others have found no exposure misclassification due to symptoms [Dale et al., 2010; Ditchen et al., 2013; Toomingas et al., 1997]. In a previous study, Toomingas et al. showed no difference in exposure estimates when subjects reported on both exposure and musculoskeletal outcomes concurrently (1997). In our cohort, we found no association between presence of upper extremity symptoms and agreement between self-reported and observed exposures [Dale et al., 2010]. As previously stated, most comparison studies have been cross-sectional assessing exposures at a single time-point, whereas the present study was longitudinal. Our prospective study design addresses many concerns about exposure misclassification through prospective collection of exposure data. Even with prospective data collection, CTS symptoms may have preceded meeting the case definition at study follow-up, and thus could have been present at the time of exposure reporting for the *most recent exposure*s. Our sensitivity analysis showed that removal of symptomatic workers from the models actually *increased* the magnitude of observed exposure-response relationships, opposite to findings that would be expected if these relationships resulted from over-reporting of exposures among subjects with symptoms present at the time of exposure reporting.

Strengths and Limitations

The main study limitation is the lack of a self-reported exposure variable to assess repetition, an exposure that has frequently been cited by previous studies as a significant risk factor for CTS [Burt et al., 2011; Shiri et al., 2009; Silverstein et al., 2010], but was not directly captured by the modified Nordstrom questionnaire utilized in this study [Nordstrom et al., 1998]. In addition, all exposure data were collected on daily duration of exposure but not on the intensity of exposure. Subjects were not asked to rate their exposures for the right and left hands separately, precluding analysis of whether the affected hand was exposed differently than the non-affected hand in subjects with unilateral CTS. Another limitation is that some subjects in our study performed additional jobs during the study period for which we do not have exposure data, for example, jobs that were held for a brief period of time in between collected surveys. Finally, the limited frequency of data collection may have led to misclassification of the outcome or exposures due to transient symptoms and variable exposures.

The major strength of the study is the prospective, longitudinal follow up of a large and varied cohort of workers. Self-reported exposures were collected at multiple time points, in most cases prior to the development of symptoms. We used a case definition for CTS based on both symptoms and median neuropathy. After workers were enrolled in the study at the time of hire in to a new job, we continued to follow them regardless of whether they remained employed with their original employer or changed jobs. Thus, we had self-reported physical exposure information available on a wide range of occupations and industries, collected over a multi-year follow-up. We simultaneously examined 3 different time patterns of self-reported physical work exposures: *most recent*, *peak*, and *employed time-weighted average exposure*. Our results showed consistent associations between CTS and workplace risk factors across these 3 approaches, lending support for the utility of self-reported exposure methods in health outcomes studies.

Conclusions

Self-reported exposure to prolonged forceful gripping, lifting, and use of vibrating hand tools predicted CTS in this large prospective study that took into account non-work risk factors for CTS. Three different time patterns of exposure identified consistent risks for incident CTS in this study. The findings of increased risk of CTS due to forceful activities (lifting and gripping) and vibrating tool use are consistent with previous studies using a variety of exposure methods. Workers' self-reported physical job demands can be collected with relative ease and lower cost than more detailed and time-intensive methods, and can provide useful information for predicting future musculoskeletal disorders and targeting specific work interventions to reduce injury risk.

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TABLE I

Demographic and clinical characteristics of the study population (N=710).

Characteristic	Mean	Standard deviation
Age (years)	30.6	10.5
Body mass index (kilograms/meters^2)	28.2	6.2
	n	**%**
Male gender	457	64.4
Diabetes mellitus	24	3.4
Baseline Job Category		
Construction	290	40.8
Clerical	262	36.9
Service	158	22.3
Self-reported physical work exposures		
Lifting objects >4 hours per day		
Most recent	254	35.8
Peak	420	59.2
Employed-time weighted	242	34.1
Using vibrating tools >4 hours per day		
Most recent	118	16.6
Peak	240	33.8
Employed-time weighted	104	14.7
Forearm rotation >4 hours per day		
Most recent	139	19.6
Peak	288	40.6
Employed-time weighted	91	12.8
Wrist bending >4 hours per day		
Most recent	245	34.5
Peak	450	63.4
Employed-time weighted	224	31.6
Forceful gripping >4 hours per day		
Most recent	173	24.4
Peak	301	42.4
Employed-time weighted	142	20.0
Thumb pressing >4 hours per day		
Most recent	139	19.6
Peak	281	39.6
Employed-time weighted	70	9.9
Finger pinching >2 hours per day		
Most recent	114	16.1
Peak	235	33.1
Employed-time weighted	113	15.9

TABLE II

Univariate logistic regression models of self-reported exposure on the epidemiological case definition of carpal tunnel syndrome (CTS) (N=710).

Self-reported exposure	CTS n (%)	No CTS n (%)	Odds ratio (95% Confidence Interval)	*p*
Lifting objects >4 hours per day				
Most recent	18 (58.1)	236 (34.8)	2.60 (1.25, 5.40)	**0.008**
Peak	25 (80.7)	395 (58.2)	3.00 (1.21, 7.40)	**0.013**
Employed-time weighted	15 (48.4)	227 (33.4)	1.87 (0.91, 3.84)	0.09
Using vibrating tools >4 hours per day				
Most recent	7 (22.6)	111 (16.4)	1.49 (0.63, 3.55)	0.362
Peak	14 (45.2)	226 (33.3)	1.65 (0.80, 3.41)	0.172
Employed-time weighted	8 (25.8)	96 (14.1)	2.11 (0.92, 4.86)	0.073
Forearm rotation >4 hours per day				
Most recent	7 (22.6)	132 (19.4)	1.21 (0.51, 2.87)	0.667
Peak	15 (48.4)	273 (40.2)	1.39 (0.68, 2.87)	0.364
Employed-time weighted	2 (6.5)	89 (13.1)	0.46 (0.11, 1.95)	0.411[a]
Wrist bending >4 hours per day				
Most recent	14 (45.2)	231 (34.0)	1.60 (0.77, 3.30)	0.202
Peak	20 (64.5)	430 (63.3)	1.05 (0.50, 2.23)	0.893
Employed-time weighted	14 (45.2)	210 (30.9)	1.84 (0.89, 3.80)	0.095
Forceful gripping >4 hours per day				
Most recent	13 (41.9)	160 (23.6)	2.34 (1.12, 4.89)	**0.02**
Peak	18 (58.1)	283 (41.7)	1.94 (0.93, 4.02)	0.071
Employed-time weighted	11 (35.5)	131 (19.3)	2.30 (1.08, 4.92)	**0.028**
Thumb pressing >4 hours per day				
Most recent	9 (29.0)	130 (19.2)	1.73 (0.78, 3.84)	0.175
Peak	13 (41.9)	268 (39.5)	1.11 (0.53, 2.30)	0.784
Employed-time weighted	1 (3.2)	69 (10.2)	0.29 (0.04, 2.19)	0.351[a]
Finger pinching >2 hours per day				
Most recent	3 (9.7)	111 (16.4)	0.55 (0.16, 1.83)	0.454[a]
Peak	9 (29.0)	226 (33.3)	0.82 (0.37, 1.81)	0.623
Employed-time weighted	4 (12.9)	109 (16.1)	0.77 (0.27, 2.26)	0.804[a]
Female gender	13 (41.9)	240 (35.4)	1.32 (0.64, 2.74)	0.454
Mean Age in years (SD)	34.3 (12.0)	30.5 (10.4)	1.03 (1.00, 1.06)	**0.049**
Mean Body mass index (kg/m^2) (SD)	31.6 (7.5)	28.0 (6.1)	1.08 (1.03, 1.13)	**0.002**

SD- Standard deviation; kg- kilograms; m-meters.

Note: Bold values indicate statistical significance, *p* <0.05.

[a]Exact test

TABLE III

Multivariate logistic regression models of three time patterns of self-reported exposure on the epidemiologic case definition of carpal tunnel syndrome, adjusted for age, gender, & body mass index (N=710).

Exposure variable[a]	Most recent exposure			Peak exposure			Employed time-weighted average exposure		
	Odds ratio (95% CI)	***p***	**AIC**	**Odds ratio (95% CI)**	***p***	**AIC**	**Odds ratio (95% CI)**	***p***	**AIC**
Lifting objects	**2.98 (1.41, 6.31)**	**0.004**	**246.00**	**3.61 (1.41, 9.24)**	**0.007**	**245.69**	**2.23 (1.05, 4.73)**	**0.036**	**249.99**
Using vibrating tools	2.04 (0.82, 5.09)	0.127	252.20	**2.24 (1.02, 4.92)**	**0.044**	**250.34**	**2.74 (1.13, 6.65)**	**0.026**	**249.91**
Forearm rotation	1.23 (0.51, 2.94)	0.643	254.10	1.36 (0.66, 2.83)	0.406	253.63	0.38 (0.09, 1.66)	0.199	252.17
Wrist bending	1.48 (0.71, 3.12)	0.295	253.24	0.98 (0.46, 2.10)	0.954	254.31	1.97 (0.94, 4.12)	0.072	251.16
Forceful gripping	**2.70 (1.26, 5.78)**	**0.011**	**248.14**	**2.21 (1.03, 4.73)**	**0.041**	**250.05**	**2.69 (1.21, 5.96)**	**0.015**	**248.88**
Thumb pressing	1.71 (0.76, 3.86)	0.199	252.77	1.12 (0.54, 2.35)	0.762	254.22	0.30 (0.04, 2.21)	0.235	252.24
Finger pinching	0.62 (0.18, 2.08)	0.436	253.63	0.87 (0.39, 1.93)	0.726	254.19	0.84 (0.29, 2.47)	0.750	254.21

CI- Confidence interval; AIC- Akaike information criterion

Note: Bold values indicate statistical significance, $p < 0.05$.

[a] All exposure variables dichotomized at >4 hours/day except finger pinching which was dichotomized at >2 hours/day.