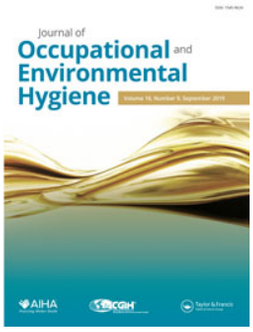

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SHORT REPORT

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Modeling the effect of the 2018 Revised ACGIH® Hand Activity Threshold Limit Value® (TLV) at reducing risk for carpal tunnel syndrome

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ABSTRACT

Recent studies have shown the 2001 American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Value (TLV®) for Hand Activity was not sufficiently protective for workers at risk of carpal tunnel syndrome (CTS). These studies led to a revision of the TLV and Action Limit. This study compares the effect of applying the 2018 TLV vs. the 2001 TLV to predict incident CTS within a large occupational pooled cohort study (n = 4,321 workers). Time from study enrollment to first occurrence of CTS was modeled using Cox proportional hazard regression. Adjusted and unadjusted hazard ratios for incident CTS were calculated using three exposure categories: below the Action Limit, between the Action Limit and TLV, and above the TLV. Workers exposed above the 2001 Action Limit demonstrated significant excess risk of carpal tunnel syndrome, while the 2018 TLV demonstrated significant excess risk only above the TLV. Of 186 total cases of CTS, 52 cases occurred among workers exposed above the 2001 TLV vs. 100 among those exposed above the 2018 value. Eliminating exposures above the 2001 TLV might have prevented 11.2% of all cases of CTS seen in our pooled cohort, vs. 25.1% of cases potentially prevented by keeping exposures below the 2018 value. The 2018 revision of the TLV better protects workers from CTS, a recognized occupational health indicator important to public health. A significant number of workers are currently exposed to forceful repetitive hand activity above these guidelines. Public health professionals should promulgate these new guidelines and encourage employers to reduce hand intensive exposures to prevent CTS and other musculoskeletal disorders.

KEYWORDS
MSD Prevention; occupational guidelines; risk assessment; upper extremity musculoskeletal disorder

Introduction

Carpal tunnel syndrome (CTS) caused by frequent, forceful hand exertions is one of the most common and costly work-related musculoskeletal disorders (MSD).[1] The American Conference of Governmental Industrial Hygienists develops voluntary workplace exposure indices, thresholds, and limits to prevent occupational injuries and illnesses due to exposure to chemical and physical agents. In 2001, a threshold limit value (TLV) for Hand Activity was published to prevent MSD among workers performing repetitive single task jobs.[2] The TLV is meant to represent conditions under which nearly all workers may be repeatedly exposed without adverse health effects; if exceeded, the risk of MSD is elevated, and control measures (e.g., engineering or administrative controls) should be employed to reduce exposure. A lower threshold, the Action Limit (AL), identifies a "moderate" risk exposure (see Figure 1A) and should trigger increased monitoring or surveillance to ensure health. Recent large studies from the U.S. and Italy examined the risk of new cases of CTS for exposures above and below the 2001 TLV and AL, and concluded that these standards were not sufficiently protective of workers.[3–5] The ACGIH subsequently revised the TLV for Hand Activity (see Figure 1B).[6] This study summarizes the effect of

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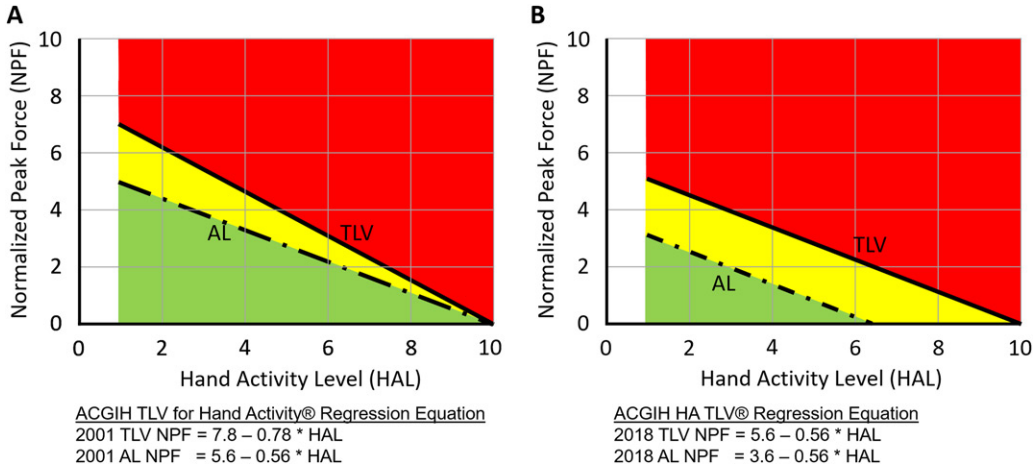

Figure 1. ACGIH TLV for hand activity regression equations for threshold limit value and action limit for (A) 2001 guidelines and (B) revised 2018 guidelines.

applying the 2018 TLV vs. the 2001 TLV to data from an occupational pooled cohort study.

Methodology

Analyzed U.S. worker cohort

The revised 2018 TLV and the 2001 version were evaluated to compare risk prediction for the AL and TLV thresholds using the same source data as Kapellusch et al.[4] Pooled data were obtained from six prospective cohort studies that investigated workplace risk factors of upper extremity MSDs. In brief, 4,321 workers, recruited by six research teams in the U.S., were followed between 2001 and 2010. All study participants were full-time employees, older than 18 years of age, who were employed in jobs that involved hand-intensive, often repetitive and forceful activities, and were employed in industries such as Manufacturing, Healthcare and Social Assistance, Services, and Construction industries.

Case definition of carpal tunnel syndrome (CTS)

Incident CTS was defined as both (1) symptoms of tingling, numbness, burning, or pain in the thumb, index finger or long finger, and (2) an abnormal electrodiagnostic studies (EDS) consistent with median neuropathy at the wrist.[7] The criteria for median neuropathy included: (1) peak median sensory latency >3.7 ms or onset median sensory latency >3.2 ms at 14 cm; (2) distal median motor latency >4.5 ms; and (3) transcarpal sensory difference >0.85 ms (difference between median and ulnar nerve sensory latency across wrist). All electrodiagnostic values were temperature adjusted to 32 °C. Symptom information was collected at baseline and at regular intervals ranging from weekly to annually during the follow-up period.[7] EDS were collected at predefined intervals in five of the six cohort studies; in the sixth study, EDS were administered to participants who reported new hand symptoms.[7] Workers were considered a CTS case on the date they met CTS symptom criteria if symptoms were reported 4 months or less prior to the date of an abnormal EDS.[7] Workers lost to follow-up prior to developing CTS were censored as a non-case on the date the worker departed the study.

ACGIH TLV for Hand Activity

The TLV considers both applied hand force and repetition of hand exertions. Trained analysts directly observed and videotaped the workers performing their usual jobs. Normalized peak hand force (NPF) was rated using the Borg CR-10 rating scale,[2] and the frequency of hand exertions was rated using the hand activity level (HAL) 0–10 scale.[8] For workers who performed multiple tasks and/or changed jobs over the follow-up period, a time-weighted-average (TWA) exposure was calculated to create a single exposure value that accounts for the proportion of daily work time in each observed task and proportion of job time during the follow-up period.

For each worker, the 2018 TLV equations were used to calculate a corresponding threshold NPF for TLV [NPF_{TLV} (Eq. 1.1)] and for AL [NPF_{AL} (Eq. 1.2)]:

$$NPF_{TLV} = 0.56 \times (10 - HAL) \quad (1.1)$$

$$NPF_{AL} = NPF_{TLV} - 2 \quad (1.2)$$

A peak force index (PFI) for TLV [PFI_{TLV} (Eq. 2.1)] and for AL [PFI_{AL} (Eq. 2.2)] were then calculated for each worker (see Figure 1B). If PFI for AL and for TLV was greater than 1.0, the respective limit was exceeded; in the case for PFI_{AL}, a negative ratio (<0) also indicated that AL was exceeded. A negative PFI_{AL} ratio occurred when HAL > 6.4 at any value for NPF_{AL}:

Table 1. Descriptive statistics and incidence density rates for ACGIH categories for 2001 and 2018 guidelines.

Variable	Mean	(SD)	Subjects	CTS Cases	Person-Years	Incidence Rate Per 100 Person Years (95% CI)
Total Cohort			2,751	186	6,282	2.96 (2.55–3.42)
Age (years)	39.6	(11.5)				
Gender						
Male			1,351	71		
Female			1,400	115		
BMI (kg/m2)	28.4	(6.1)				
NPFOBS (Borg CR-10) – TWA	2.8	(1.7)				
HAL (0–10) – TWA	4.3	(1.8)				
ACGIH (2001) Exposure Categories						
<AL			1,585	86	3,879	2.22 (1.77–2.74)
≥AL and ≤TLV			529	48	1,219	3.94 (2.90–5.22)
> TLV			637	52	1,185	4.39 (3.28–5.76)
ACGIH (2018) Exposure Categories						
<AL			649	34	1,618	2.11 (1.46–2.94)
≥AL and ≤TLV			936	52	2,261	2.30 (1.72–3.02)
>TLV			1,166	100	2,404	4.16 (3.39–5.06)

$$\mathrm{PFI_{TLV}} = \mathrm{NPF_{OBS}}/\mathrm{NPF_{TLV}} \quad (2.1)$$

$$\mathrm{PFI_{AL}} = \mathrm{NPF_{OBS}}/\mathrm{NPF_{AL}}. \quad (2.2)$$

Using both $\mathrm{PFI_{TLV}}$ and $\mathrm{PFI_{AL}}$, workers were categorized into: (1) *below AL*, (2) *between AL and TLV*, and (3) *above TLV*. To determine exposure classifications using the 2001 TLV, a score (Eq. 3) was calculated and subsequently categorized workers into: *below AL* (score ≤ 0.56), *between AL and TLV* (score between 0.56 and 0.78), and *above TLV* (score ≥ 0.78):

$$Score = NPF_{OBS}/(10 \ - HAL). \quad (3)$$

Statistical analysis

After excluding participants who had prevalent CTS at baseline (n = 396), no follow-up measurements (n = 410), incomplete outcome data (n = 159), no biomechanical exposure data (n = 430), or missing peak force or HAL measures (n = 147), the pooled cohort was reduced to 2,751. At the time of enrollment, the demographics were similar between the full cohort of 4,321 workers and the analyzed cohort of 2,751 workers: average age [full cohort = 38.5 years (range: 18.0 – 72.7), analyzed cohort = 39.6 years (range: 18.0 – 68.6)], mean BMI [full cohort = 28.6 (SD = 6.3), analyzed cohort = 28.4 (SD = 6.1)], distribution based on sex [full cohort = 48.4% female, 51.5% male, analyzed cohort = 50.9% female, 49.1% male], and proportion of workers in mono-task jobs [full cohort = 62.3%, analyzed cohort = 71.9%].[4,7] Descriptive statistics were calculated for the 2001 and the 2018 TLV and AL classifications. Person-years and CTS incidence density rates were calculated for each exposure category. Proportions of CTS cases was compared for the three TLV categories between 2001 and 2018 TLVs with the chi-square test. To estimate differences in the number of cases of CTS attributable to work exposures above the TLV, we compared unadjusted incidence rates of CTS (cases/100 person-years) for those exposed above the 2001 and 2018 TLVs to those exposed below the TLVs. Based on these incidence rates we then calculated the Attributable Proportion of CTS related to exposure for cases occurring in workers exposed above the TLV. Time from study enrollment to first occurrence of CTS was modeled using Cox proportional hazard (PH) regression. Both unadjusted and adjusted (co-variates: age, BMI, gender, and research site) hazard ratios (HR) were calculated for incident CTS using the three exposure categories. Co-variates were selected *a priori* as personal risk factors associated with increasing risk of developing CTS.[3–5,7] All analyses were performed using SAS (version 9.4, SAS Institute, Cary, NC).

Results

The 2,751 workers in the pooled cohort contributed 6,282 person-years of observation time over a maximum 6.4 years of follow-up (Table 1). There were 186 incident cases of CTS with an overall incident density rate of 2.96 cases per 100 person-years. Application of the 2018 exposure recommendations markedly changed the categorization of exposures within our worker cohort. 42.4% of workers were classified as above the 2018 TLV vs. 23.2% above the 2001 TLV; 23.6% of workers were exposed below the 2018 AL vs. 57.6% of workers below the 2001 AL; and 34% vs. 19.2% classified as between the AL and TLV in 2018 and 2001, respectively. The 2001 and 2018 TLVs had significantly different proportions of incident CTS cases within the three TLV categories ($\chi^2(2) = 37.851$, $p < 0.05$), reflecting fewer cases of CTS occurring below the 2018 TLV and AL, and more cases occurring above the TLV. For exposures below the AL, the 2018 threshold identified

Table 2. Crude and adjusted associations between TLV for HAL categories and incident CTS.

	2001 ACGIH for Hand Activity			2018 ACGIH HA TLV		
Variable	HR	(95%CI)	p > ChiSq	HR	(95%CI)	p > ChiSq
Unadjusted						
<AL	1.00			1.00		
≥AL and ≤TLV	1.80	(1.27–2.57)	0.0011	1.12	(0.72–1.72)	0.6171
>TLV	2.01	(1.41–2.84)	<0.0001	2.03	(1.37–3.00)	0.0004
Adjusted for BMI, age, gender, research site						
<AL	1.00			1.00		
≥AL and ≤TLV	1.88	(1.30–2.72)	0.0007	1.16	(0.73–1.85)	0.5225
>TLV	1.73	(1.20–2.49)	0.0034	1.99	(1.28–3.10)	0.0021

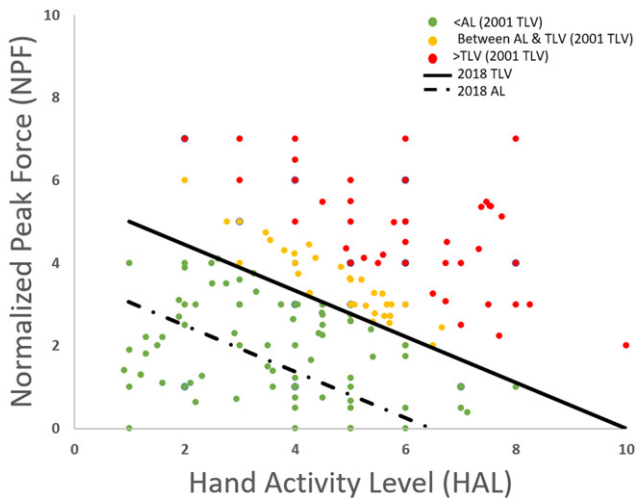

Figure 2. Cases of CTS (n = 186) by exposure to Normalized Peak Force and Hand Activity Level. CTS cases plotted onto the 2018 TLV and color coded with 2001 TLV categories.

52 fewer cases compared to the 2001 threshold (2001 TLV: 86 CTS cases; 2018 TLV: 34 cases). Below the TLV, the 2018 threshold identified 48 fewer cases compared to the 2001 threshold (2001 TLV: 134 total CTS cases; 2018 TLV: 86 total cases). Above the TLV, the 2018 threshold identified 48 more cases than the 2001 threshold (2001 TLV: 52 CTS cases; 2018 TLV: 100 CTS cases). Table 2 shows large and statistically significant excess risk of incident CTS occurring above both the AL and above the TLV when using the 2001 exposure recommendations. Under the 2018 TLV and AL, significant excess risk was seen only above the TLV.

Attributable proportion of CTS related to exposure above the TLV was 0.401 for the 2001 TLV and 0.467 for the 2018 TLV. This suggests that eliminating exposure above the TLV for all workers would have prevented 20.9 cases of CTS (11.2% of all cases in the cohort) using the 2001 limit, and 46.7 cases (25.1% of cases) using the 2018 TLV. For both the 2001 and 2018 recommendations, further reductions would be achieved by eliminating exposures above the AL.

Figure 2 shows the distribution of CTS cases in our pooled cohort, graphed against NPF and HAL. There is a broad range of exposures represented by these cases without clear clustering by force or activity. The 2018 TLV and AL are shown for reference; cases are color coded by their exposure category under the 2001 TLV and AL. All CTS cases that occurred in workers above the 2001 AL but below the 2001 TLV are above the 2018 TLV, graphically demonstrating previous findings that the 2001 AL was insufficiently protective.

Discussion

Work-related MSDs remain a burden in the U.S., with substantial employer and societal costs and impacts on the affected individual's quality of life. For example, estimated medical care costs of CTS exceed $2 billion annually,[9] a number that does not include disability and other social costs. Importantly, CTS has the second highest rate of opioid prescribing by injury type among workers treated in under workers compensation.[10] Treatment of work-related disorders with prescription opioids has contributed to the current epidemic of opioid-related deaths,[11] with higher rates seen in industries with the highest injury rates.[12] Risk assessment and control methods exist for work-related MSDs, including ACGIH TLV designed to prevent upper extremity MSDs such as CTS. This study evaluated the recommended 2018 TLV as thresholds for risk factors of CTS using a large pooled cohort representing a diverse workforce in dozens of occupations and industries in the U.S. The 2001 TLV demonstrated little risk difference between exposures above the TLV and between the AL and the TLV when compared to exposures below the AL, whereas the 2018 TLV demonstrated significant risk only above the TLV. Importantly, a substantial number of workers in our pooled cohort were exposed above the 2001 and 2018 TLVs recommended by ACGIH, indicating an ongoing need to reduce exposures to prevent CTS and other upper extremity MSDs among workers in hand-intensive jobs.

In practical terms, if the 2018 TLV was used for surveillance on this pooled cohort, and if subsequent

ergonomic interventions had been performed at the outset of the study to reduce exposure to those above the AL, then the 2018 TLV might have prevented 28% of CTS cases that occurred below the 2001 AL. Similarly, 26% of workers classified as below TLV by the 2001 thresholds would have been classified as above TLV by the 2018 threshold and might also have been prevented. Thus, these hypothetical biomechanical exposure reducing interventions might have lowered the incidence rate of CTS for the pooled cohort by 28% from 2.96–2.11 per 100 person-years. Future epidemiological studies might help improve precision of risk estimates for hand repetition and force and upper extremity MSD, thereby refining the sensitivity and specificity of guideline thresholds.

The findings from this report are subject to at least three limitations. First, at baseline, workers reported an average of 7.6 years (SD = 8.6) of tenure within their company and are likely representative of a survivor population. Therefore, study findings probably underestimate risks of exposure and the effect sizes may be somewhat lower than what would have been found in a population of newly hired workers. Second, workers who changed jobs over the follow-up period (n = 683) were assigned a time-weighted-average for peak force and HAL measurements, which could have resulted in non-differential misclassification of exposure. However, incident density rates were comparable between the full cohort using the TWA approach and the cohort of workers who reported only a single job (n = 2,068). Job variability did not appear to affect our interpretation of the exposure-response associations. Third, despite the increased statistical power and increased generalizability, there were challenges in pooling health outcome data from six studies.[4,7] While analysts received similar training on rating of peak force and HAL,[4] other test procedures varied across studies, including the frequency of CTS assessment and protocols used to collect symptom and EDS results. Essential similarities across these research studies allowed us to create common exposure measures and a common case definition of CTS.[7] Our analyses included research site as a covariate to account for potential differences between sites.[13]

Conclusion

CTS is a recognized occupational health indicator of the working population important to public health.[14] The 2018 TLV is demonstrated to improve the protection of workers who perform hand intensive tasks from risk of CTS. Adherence to the 2018 TLV might have prevented 28% of CTS cases that occurred below the 2001 AL; 26% of CTS cases classified as below TLV by the 2001 thresholds would have been classified as above the TLV by the 2018 threshold. Many workers in hand intensive industries are still exposed above recommended limits.

Recommendations

As part of a robust occupational health and safety program, adhering to the 2018 TLV could be a key primary prevention strategy to reduce the public health burden of CTS and other upper extremity MSDs. In practice, the 2018 TLV may be used to prioritize tasks for further investigation and for potential control efforts. We found that the revised 2018 TLV was an effective tool for predicting risk of CTS in our pooled cohort and should thus be used to trigger control measures when these limits are exceeded. When the AL or TLV are exceeded, employers should make changes (e.g., engineering controls and administrative controls) to the work environment to reduce workers' exposure to forceful, repetitive hand activities.

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