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Original Article

Powered-hand tools and vibration-related disorders in US-railway maintenance-of-way workers

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Abstract: Maintenance-of-way workers in North America who construct railroad tracks utilize specialized powered-hand tools, which lead to hand-transmitted vibration exposure. In this study, the maintenance-of-way workers were surveyed about neuro-musculoskeletal disorders, powered-hand tools and work practices. Information about vibration emission data of trade specific powered-hand tools for the North American and European Union markets was searched online to obtain respective user information of manufacturer and compared to non-commercial international data banks. The survey showed that maintenance-of-way workers frequently reported typical hand-transmitted vibration-related symptoms, and appear to be at a risk for neuro-musculoskeletal disorders of the upper extremity. Of all of the powered-hand tools used by this trade, 88% of the selected tools exceeded a=5 m/s^2 and were above vibration magnitudes of common tools of other comparable industries. This may create a risk if these tools are used throughout an 8-h work day and management of vibration exposure may be needed. In the North-American market, limited or no vibration emission data is available from manufacturers or distributors. Vibration emission information for powered-hand tools, including vibration emission levels (in m/s^2), uncertainty factor K, and the applied testing standard/norm may assist employers, users and occupational health providers to better assess, compare and manage risk.

Key words: Ergonomics, Segmental vibration, Neuro-musculoskeletal disorders, Prevention, Railroad

Introduction

It has been estimated that more than 1.5−2 million workers in the United States (U.S.) are regularly exposed to hand-arm vibration (HAV) (also described as hand-transmitted vibration, or HTV) at work[1)]. In addition, according to an expert opinion, more than 1 million workers are exposed to hand-transmitted vibration for more than 30 min/d (personal communication 12/2019: Dong, Renguang G. (CDC/NIOSH/HELD/PERB) 10/2019). This includes powered-hand tool operators in the construction, farming, metal/steel, lumber and wood, mining, foundries and vehicle manufacturing industries. It does not include maintenance-of-way (MoW) workers, who build and maintain the more than 140,000 miles of rail network in the U.S., which are owned by the 600 railroad companies, including the 7 large class-one railroad corporations.

Little is known in the medical literature about MoW workers, also known as trackmen or section crew laborers, and their specific occupational exposures. These MoW workers often work in teams of 6 to 9 individuals or more. They travel in road or off-road vehicles to work sites throughout large areas of the USA. Although the work characteristics and job duties of the MoW worker are often

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compared to general construction workers, there are a number of specific and important differences. MoW workers are generally involved in the maintenance and repair of track defects and track conditions, emergency repairs, new construction of track, bridges, buildings and other structures, and right-of-way (i.e., access roads) maintenance operations. This work often entails the use of heavy old-style hand tools, but is progressively making use of powered-hand tools and automated equipment/vehicles that expose workers to vibration and other ergonomic physical hazards. Many of these tools are unique and different from the general construction industry[2, 3]. MoW workers typically work with steel, iron, timber and concrete. Work tasks include ground preparation, ballast and earth handling, welding, grinding, cutting, sewing, drilling, bending, lifting of tracks and ties, hammering, nailing, and nuts and bolts manipulation[4]. The work is primarily performed outdoors during all seasons with extremes of heat, cold, rain, wetness and humidity. Shift-work schedules involving overtime, including nights, weekends and holidays, are not uncommon.

MoW tool and machine operators are likely exposed to multiple occupational hazards. However, HAV exposure from powered-hand tools represents a “constant factor” that cumulatively may add up to several thousands of hours of exposure during a lifetime of work. A multitude of musculoskeletal symptoms and disorders were recognized among MoW workers in a recent comprehensive health survey, sponsored by the Brotherhood of Maintenance of Way Employees (BMWED), and included injuries and disorders which involved the upper extremities, neck, back and lower extremities[5, 6].

HAV exposure is recognized as a causative factor for musculoskeletal and neuro-vascular disorders, such as carpal tunnel syndrome (CTS) and vasospastic disease i.e. white-finger syndrome (Raynaud’s syndrome, also known as HAV syndrome), and the necessity of preventive guidelines has been shown[7–9]. In European countries, such as in Germany as early as 1929 (and 1977), degenerative skeletal or neuro-vascular injuries to the wrist and hand(s) have been specifically recognized as an occupational disease category[10, 11], and work place risk assessments are required[12]. In the European Union (EU), legal requirements obligate the employer and others to investigate and protect workers from harmful and preventable vibration (Directive 2002/44/EC) if tool emissions exceed a certain “action value” and “exposure limits value”[13, 14]. And in Japan, already in 1947, the Ministry of Labor recognized vibration syndrome among operators of rock drills and riveters as an occupational disease, and clinical diagnostic guidelines were subsequently established early on[15]. Specific workplace monitoring programs and assistance, technical-ergonomic interventions and educational tools regarding HAV prevention efforts are all in place in these countries.

The specific goals of the current study were:

1) Investigate adverse health outcomes related to the musculoskeletal and neuro-vascular system of the upper extremities among powered-hand tool operators.

2) Identify specific powered-hand tools frequently used by MoW workers.

3) Study powered-hand tool emission listings for users in the NA and/or the EU markets and what technical details are reported, and compare these to non-commercial data.

4) Identify powered-hand tools with high vibration emissions that may exceed exposure thresholds if used alone or in combination with other tools throughout a typical 8-h work day as defined by the European Union Machine Directive.

Subjects and Methods

A comprehensive survey addressing work practices, work factors and health was sent to approximately 34,580 current BMWED members and 3,975 active retirees. Survey responses were received between August 1, 2016 and February 28, 2017 from “active” BMWED members, those out on disability, and those retired due to age or medical condition at the time of the survey. 4,816 members and retirees answered the survey in full or in part, amounting to approximately a 12% response rate. A subset of survey non-responders was also surveyed to assess possible selection bias. There were minimal differences in age, job-seniority, gender and regions of survey responders versus non-responders (age: 42.7 yr vs. 44.5 yr, seniority: 12.7 yr vs. 14.9 yr, gender: 99% male) (further details are provided in[5] and its online supplemental data). Compared with non-respondents, active members and retirees who completed the survey were younger, had slightly better working conditions, and tended to be healthier (except for back pain)[5]. This suggests that our current analysis may actually underestimate the associations between working conditions and musculoskeletal symptoms among MoW workers[6].

Our analysis was conducted as part of a project funded by the Union of MoW workers, the Brotherhood of Maintenance of Way Employes Division (BMWED) of the

International Brotherhood of Teamsters. Participants were encouraged to fill out the confidential survey online (English or Spanish) or complete a paper survey. No personal identifiers were collected and survey replies were recorded anonymously. The survey ascertained demographics, work history, use of vehicles and tools, work factors, symptoms, illnesses and injuries, and the social and economic impact of work-related injuries and illnesses. Institutional Review Board (IRB) approvals came from both Cook County Hospital (Chicago, IL) and the State University of New York-Downstate Medical Center (Brooklyn, NY, USA). To ensure that the identity of all survey participants would be legally protected from discovery, a Certificate of Confidentiality was issued by the National Institutes of Health (NIH).

The survey included questions about the job tenure and job title of the survey participants, and included questions from the VibRisks epidemiological study project of HTV[16, 17]. Specific questions regarding biomechanical workplace factors were queried, the most pertinent of which to our investigation includes the following:

Segmental vibration. "What tool(s) have you operated at work since you started working for the railroad, and for how many years and hours per typical day have you worked with them?" ("report only if you have done/handled this tool for more than one year".) *Powered-hand tools*: Jack hammer, rock drill, concrete vibrator, hammer drill, nail gun, reciprocating saw, rivet buster, scabbler, air hammer, impact wrench, nut splitter, tamping gun (hand held), profile grinder, spike puller, spiker gun, spike driver, rail saw, impact tool, grinder, asphalt tamper, rail drill.

Bothered by vibration. "How many hours during your workday do you face either of the following: "Vehicle/equipment vibration bothers me" (not analyzed here) or "Hand tool vibrations bother me"? (8–10 h/d, 4–6 h/d, 1–2 h/d, <1 h/d, 0 h)[18–20].

In order to construct a measure of segmental vibration exposure for each of the 21 powered-hand tools, we combined data from a question on years of use ("About how many years have you used these tools?") and fraction of a day using the tool ("About how often do you use this (these) tools in a typical day?" ("Always", "Often", "Sometimes", "Rarely", or "Never")). Each daily-use frequency category was assigned a respective weight; "Always" was given a value of 1.00, "Often" was given a value of 0.75, "Sometimes" was given a value of 0.50, "Rarely" was given a value of 0.25, and "Never" was given a value of 0.0. MoW workers who indicated that they had not used a given tool during their employment for the railroad were recorded as using that tool for zero years, with a daily-use frequency of "Never". A quantifiable measure of 10 yr cumulative risk for each tool was then calculated by multiplying the weighted frequency values by the number of years a participant utilized a given tool (with "non-users" assigned a zero value).

This composite measure of segmental vibration was used to compare the differing levels of exposure among the powered-hand tools, as well as explore any significant association between duration of exposure to these tools and selected neuro-vascular and musculoskeletal symptoms and disorders. A focus of this study is the diagnoses of carpal tunnel syndrome (CTS) and HAV related disorder.

Vibration emission and exposure risk

In addition to the MoW survey, the vibration emission information from manufacturers or distributors of powered-hand tools used in the railroad industry were searched on the internet. For various logistical and legal reasons, actual field measurements could not be performed as part of the MoW survey study. Vibration emission data published by manufacturers or distributors of special railroad powered-hand tools was searched in sales catalogs, specification sheets or user manuals provided for the North American (NA) and EU markets. Such commercial information was compared if available with non-commercial data, found in online vibration data-banks or publications from regulatory agencies, academic resources (e.g., from Germany, Sweden, Italy and UK) or other publications. The web search engines of *Google, Mozilla Firefox (version 77.0.1 including duckduckgo)* and the Microsoft Edge (Version 83.0.478.50) browsers were utilized to obtain vibration emission data separately from the NA and EU market regions (primarily Germany, France, Italy, Spain und the UK) (results as of December 2019). In order to overcome country specific website customization and possible information limitations due to geo-blocking, as well as obtain manufacturer information designed for customers/users of specific geographical regions (regional internet registries: ARIN and RIPE NCC), a search engine browser VPN extension (ZenMate, Version 5.0.13.5607) was utilized using the same search terms (manufacturer [name] and specific tool descriptions) for the NA and (for comparison in) the EU markets. In addition, vibration data from independent, regulatory or governmental sources were compared with obtained manufacturer information, for example the Network Rail in the UK[21], available online via vibration-measurements data-banks or other references. If the emission information was not listed on the manufacturers' web-sites, catalogues or specification sheets, the tool manual was checked for vibration emission information. In contrast to NA, in the EU, the EU Machinery Directive mandates that manufacturers and distributors inform the buyer/user of powered-hand tools about vibration emissions exceeding any acceleration of a=2.5 m/s^2 in a typical 8-h work day[12, 13]. The recommended listing of the vibration emission, un-certainty value "K" and the applied norm following the existing declaration guidelines were also checked.

Statistical analysis

Our analyses of exposures and health outcomes were restricted to active male MoW participants under 75 yr old. This inclusion criteria and subsequent analyses are consistent with previous work performed on the data[5].

Descriptive information of particular interest to this investigation includes the following: 1. Demographic information—age, ethnicity, geographical regions of employment, and smoking status, and 2. Musculoskeletal outcomes—six outcomes in total, with three pertaining to pain experienced over the past week in the shoulders, elbows, or hands/wrists, respectively, while three refer to the clinical diagnoses of CTS, finger numbness/tingling, and clearly demarcated white fingers (the latter two being consistent with HAV syndrome).

Primary hypotheses were that segmental vibration exposure from each of the respective 21 powered-hand tools mentioned would be associated with the aforementioned six musculoskeletal outcomes. A total of 126 (i.e., 21 times 6) Poisson regression analyses were run (using GENLIN in SPSS v. 26), adjusted for age, region of the country the participant worked, race/ethnicity, smoking status, second job potential vehicle vibration exposure, and spare time potential vehicle vibration exposure. Each regression analysis assessed the adjusted prevalence ratio (aPR) and associated 95% confidence interval (95% CI) of having the musculoskeletal outcome.

Results

Survey results

Demographics of the surveyed MoW workers are listed in Table 1. Among 3,995 active survey participants, 70 individuals were excluded due to age restrictions and 18 for reporting being female, leaving 3,907 participants available for this analysis. Also, it should be noted that due to the small number of reported female participants, 1,159 active workers <75 yr old who were missing data on gender were included in the analysis, due to their high likelihood of being male. In a previous manuscript, sensitivity analyses excluding all respondents missing data on gender revealed no declines more than 9% in the magnitude of any significant association between work exposures and neck, back and knee symptoms, with the exception of use of high vibration vehicles more than 1.9 yr and knee pain, which declined from an aPR of 1.38 to an aPR of 1.27[6]. Therefore, we chose to include all 1,159 active workers <75 yr old who were missing data on gender in our analyses.

Table 1. Demographics of MoW worker survey participants

	Number (%)	Mean	Min/Max
Survey participants	3,907		
Age		42.7	20 / 75
Ethnicity:			
White	2,252 (57.6%)		
Non-white	489 (7.4%)		
Unknown	1,166 (29.8%)		
U.S. Work regions:			
Northeast	1,013 (25.9%)		
Southeast	535 (13.7%)		
Central/Midwest	1,663 (42.6%)		
Western	690 (17.7%)		
Smoking status (yes)	272 (9%)		

MoW: maintenance of way. Among the 3,995 active survey participants, 69 were excluded from analysis for missing age, one for reporting their age ≥75, and 18 for reporting being female, leaving 3,907 participants available for analysis. The 1,159 participants <75 yr old who were missing data on gender were included in the analyses due to their high likelihood of being male.

The mean age of these 3,907 male MoW workers was 42.7 yr. The current smoking prevalence was 9%, compared to the US national prevalence of 13.8% in 2018 (Source: NCHS, National Health Interview Survey, Sample Adult Core component)[22].

Health outcomes

The health survey revealed that, compared to all U.S. employed men aged 18–74[22, 23], active BMWED men were more likely to have been told by a doctor or a health professional that they have carpal tunnel syndrome (CTS) (8.2% vs. 3.6%) (unadjusted odds ratio=2.27, 95% CI 1.90–2.71, p<0.001). Table 2 shows the prevalence of different musculoskeletal complaints & diagnoses among the 3,907 surveyed (note each outcome is composed of both respondents to the pertinent question(s) & non-respondents whose answers were missing). Pain in the upper extremities, specifically within the hands, wrists, or shoulders, was prevalent in about 16% to 18% of MoW workers. A smaller proportion of MoW workers surveyed reported daily or weekly symptoms during the past year, consistent with vibration-related disease—fingers going white (blanching) when exposed to cold (n=143, 3.7%), and having experienced white fingers where the whiteness was clearly demarcated (showed clear limits or boundaries) (n=77, 2.0%). In addition, 8.0% (n=314) reported difficulty picking up very small objects, such as screws or buttons, or opening tight jars.

Tables 3 and 4 both show powered-hand tools ranked according to each tool's average segmental vibration among MoW workers. These average duration of full-time equivalent exposure values ranged from 5.04 yr of vibration exposure (impact wrench) to 0.06 yr of vibration exposure (scabbler). Also noteworthy is that 50% of users of nine of the ten highest ranked tools in the tables indicated that they "always" or "often" used that tool.

A significantly increased risk of pain was seen after 10 yr (x fraction of a day) use of various powered-hand tools, ranging from 32% (asphalt tamper, n=336) to 71% (nut splitter, n=176) increased risk. Significantly elevated risks were also reported for specific powered-hand tools, in relation to shoulder, elbow, or hand/wrist pain (Table 3).

In addition, increased risks for health outcomes effecting the upper extremity, including typical symptoms for CTS and HAV-syndrome, such as paresthesias (numbness/tingling) and the typical white-finger demarcation, were seen for a variety of tools; in particular, these tools include impact tools (wrenches), spike tools, drills, saws and grinder (Table 4).

MoW workers who reported having a diagnosis of CTS or symptoms of Vibration White Finger (VWF) also reported an increasing likelihood of being "bothered by vibration" with each increasing level of exposure duration (from 1–2 h/d, to 4–6 h/d, through to 8–10 h/d), as compared to MoW workers with no hand tool exposure. While only 2% of active male BMWED members reported symptoms of CTS if hand tool equipment vibration did not bother them, at least 7% of members reported these symptoms if hand tool equipment vibration bothered them at least sometimes (1–2 h/d). Similarly, while only 1% of active male BMWED members reported symptoms of VWF if hand tool equipment vibration did not bother them, 17.0% of members reported these symptoms if hand tool equipment vibration bothered them often or always (8–10 h/d) (Table 5).

Table 2. Health outcomes/complaints reported by MoW worker survey participants (n=3,907)

Musculoskeletal symptoms/Diagnoses	Categories	N	% of n
Shoulder pain during past week lasting a day or more	Yes	657	16.8
	No	2,351	60.2
	Total	3,008	77
	Missing	899	23
Elbow pain during past week lasting a day or more	Yes	407	10.4
	No	2,601	66.6
	Total	3,008	77
	Missing	899	23
Hand/wrist pain during past week lasting a day or more	Yes	686	17.6
	No	2,322	59.4
	Total	3,008	77
	Missing	899	23
Diagnosed by a doctor with carpal tunnel syndrome	Yes	247	6.3
	No	2,761	70.7
	Total	3,008	77
	Missing	899	23
Experiencing finger numbness or tingling daily or weekly	Yes	716	18.3
	No	2,146	54.9
	Total	2,862	73.3
	Missing	1,045	26.7
Experiencing white fingers from the cold or clear boundary daily or weekly	Yes	149	3.8
	No	2,685	68.7
	Total	2,834	72.5
	Missing	1,073	27.5

MoW: maintenance of way.

Vibration emission

Vibration magnitudes (root-mean-square value) measured on tool handles of commonly used hand-tools for MoW-workers (as listed by manufacturers) and for comparison of independent sources are shown in Table 6 and Fig. 1. A comparison of the vibration emissions of 75 powered-hand tools and from the 23 leading North American (NA) and European Union (EU) tool manufacturers, disclosed either no, partial, conflicting or inconsistent vibration emissions information. Vibration data provided by manufacturers according to the EU Machinery Directive 2006/42/EC may for practical purpose provide estimates of vibration exposures without making vibration measurements[24]. However, these do not include the exposure duration of a worker which is used to calculate the actual A (8)-value, which is a combined measure of the exposure magnitude and time duration of tool use.

Table 3. Analyses of tool-related work exposures and shoulder, elbow and hand/wrist symptoms reported by MoW worker survey participants ranked by the frequency of tool use (adjusted for age, region, race/ethnicity, smoking, second job vehicle vibration, spare time vehicle vibration). Active BMWED men (n=3,907)

Power hand tool		n	Average total tool use (years used × daily frequency of tool use)	Shoulder pain in past week lasting a day or more			Elbow pain in past week lasting a day or more			Hand/wrist pain in past week lasting a day or more		
				N=[2,787]			N=[2,787]			N=[2,787]		
				Adjusted PR	95% CI	*p*	Adjusted PR	95% CI	*p*	Adjusted PR	95% CI	*p*
Risk for 10 yr (× fraction of day) worked with:	IMPACT WRENCH	2,512	5.04	1.29	1.15, 1.45	<0.001	1.40	1.22, 1.61	<0.001	1.38	1.24, 1.53	<0.001
	IMPACT TOOL	2,413	4.88	1.36	1.22, 1.53	<0.001	1.51	1.32, 1.72	<0.001	1.42	1.28, 1.58	<0.001
	SPIKE PULLER	2,772	4.85	1.36	1.21, 1.54	<0.001	1.46	1.26, 1.68	<0.001	1.34	1.19, 1.50	<0.001
	RAIL SAW	2,634	4.82	1.34	1.19, 1.50	<0.001	1.39	1.21, 1.60	<0.001	1.32	1.18, 1.47	<0.001
	RAIL DRILL	2,565	4.65	1.29	1.15, 1.44	<0.001	1.35	1.17, 1.54	<0.001	1.27	1.14, 1.42	<0.001
	SPIKE DRIVER	2,368	4.41	1.27	1.13, 1.43	<0.001	1.46	1.27, 1.68	<0.001	1.32	1.18, 1.48	<0.001
	SPIKER GUN	2,076	3.84	1.27	1.13, 1.43	<0.001	1.43	1.25, 1.64	<0.001	1.31	1.17, 1.47	<0.001
	GRINDER	2,184	3.68	1.33	1.18, 1.49	<0.001	1.41	1.23, 1.62	<0.001	1.37	1.23, 1.53	<0.001
	Tamping gun (hand held)	2,347	3.09	1.55	1.34, 1.79	<0.001	1.55	1.29, 1.86	<0.001	1.49	1.29, 1.71	<0.001
	PROFILE GRINDER	1,670	2.24	1.30	1.13, 1.50	<0.001	1.40	1.19, 1.65	<0.001	1.35	1.19, 1.54	<0.001
	Jack Hammer	1,223	1.40	1.43	1.21, 1.68	<0.001	1.51	1.25, 1.83	<0.001	1.39	1.18, 1.62	<0.001
	Reciprocating saw	820	1.00	1.41	1.15, 1.73	0.001	1.55	1.23, 1.95	<0.001	1.33	1.09, 1.63	0.006
	Air hammer	645	0.88	1.27	1.04, 1.55	0.018	1.42	1.14, 1.76	0.002	1.32	1.10, 1.58	0.003
	Hammer drill	731	0.84	1.35	1.10, 1.64	0.004	1.49	1.20, 1.86	<0.001	1.33	1.10, 1.61	0.003
	Rock drill	328	0.37	1.16	0.82, 1.63	0.413	1.62	1.17, 2.25	0.004	1.46	1.11, 1.93	0.007
	Concrete vibrator	395	0.34	1.40	0.99, 1.97	0.055	1.66	1.15, 2.41	0.007	1.54	1.13, 2.09	0.006
	Asphalt tamper	336	0.31	1.65	1.18, 2.32	0.004	1.81	1.24, 2.66	0.002	1.21	0.82, 1.80	0.344
	Nail gun	258	0.29	1.20	0.82, 1.75	0.36	1.46	1.00, 2.14	0.048	1.04	0.70, 1.56	0.839
	Rivet buster	214	0.23	1.09	0.74, 1.61	0.657	1.49	1.05, 2.12	0.025	1.31	0.96, 1.79	0.087
	Nut splitter	176	0.21	1.82	1.26, 2.64	0.001	2.45	1.68, 3.57	<0.001	1.70	1.17, 2.47	0.005
	Scabbler	55	0.06	0.63	0.17, 2.29	0.481	1.34	0.53, 3.36	0.536	1.29	0.59, 2.82	0.516

Among the 3,907 active male participants ≤75 yr old, due to missing information among regression covariates, exposure and health data, only 2,787 participants were included in each of these regression analyses.

The frequency of daily use at work of a given tool was recorded as "Always", "Often", "Sometimes", "Rarely", or "Never", amongst participants who indicated that they had utilized said tool at some point during their employment for the railroad. These frequency categories were assigned the respective weights of 1.00, 0.75, 0.50, 0.25, and 0.00, and multiplied by the number of years participants utilized a given tool, to acquire a quantifiable measure of effective tool use. The tools are ranked in the table, according to this measure.
Tools where a majority of participants (>50%) indicated that they "Always" or "Often" use it daily at work, are listed in capital letters.
MoW: maintenance of way; BMWED: Brotherhood of Maintenance of Way Employees; n: number of participants among the 3,907 who had any exposure associated with the given tool; N: number of participants for regressions within a given outcome; PR: prevalence ratio; CI: confidence interval; *p*: *p*-value.

Table 4. Analyses of tool-related work exposures and hand/wrist related symptoms/diagnoses reported by MoW worker survey participants ranked by the frequency of tool use (adjusted for age, region, race/ethnicity, smoking, second job vehicle vibration, spare time vehicle vibration). Active BMWED men (n=3,907)

Power hand tools		n	Average total tool use (years used × daily frequency of tool use)	Told by a doctor they have carpal tunnel syndrome N=[2,787]			Finger numbness or tingling daily or weekly N=[2,677]			White fingers from cold or clear boundary daily or weekly N=[2,655]		
				Adjusted PR	95% CI	*p*	Adjusted PR	95% CI	*p*	Adjusted PR	95% CI	*p*
Risk for 10 yr (× fraction of day) worked with:	IMPACT WRENCH	2,512	5.04	1.38	1.17, 1.63	<0.001	1.31	1.18, 1.46	<0.001	1.47	1.18, 1.84	0.001
	IMPACT TOOL	2,413	4.88	1.53	1.31, 1.79	<0.001	1.35	1.21, 1.50	<0.001	1.46	1.16, 1.83	0.001
	SPIKE PULLER	2,772	4.85	1.58	1.35, 1.86	<0.001	1.36	1.21, 1.52	<0.001	1.58	1.25, 2.01	<0.001
	RAIL SAW	2,634	4.82	1.47	1.25, 1.73	<0.001	1.25	1.11, 1.39	<0.001	1.29	1.01, 1.65	0.038
	RAIL DRILL	2,565	4.65	1.41	1.20, 1.65	<0.001	1.23	1.10, 1.38	<0.001	1.51	1.21, 1.89	<0.001
	SPIKE DRIVER	2,368	4.41	1.57	1.34, 1.84	<0.001	1.32	1.18, 1.48	<0.001	1.52	1.20, 1.92	<0.001
	SPIKER GUN	2,076	3.84	1.51	1.29, 1.77	<0.001	1.39	1.24, 1.55	<0.001	1.74	1.40, 2.16	<0.001
	GRINDER	2,184	3.68	1.39	1.17, 1.64	<0.001	1.32	1.18, 1.48	<0.001	1.50	1.20, 1.89	<0.001
	Tamping gun (hand held)	2,347	3.09	1.49	1.19, 1.85	<0.001	1.43	1.24, 1.65	<0.001	1.84	1.37, 2.47	<0.001
	PROFILE GRINDER	1,670	2.24	1.43	1.19, 1.73	<0.001	1.27	1.11, 1.46	<0.001	1.30	0.97, 1.74	0.076
	Jack Hammer	1,223	1.40	1.65	1.34, 2.04	<0.001	1.41	1.21, 1.65	<0.001	1.69	1.25, 2.29	0.001
	Recipro-cating saw	820	1.00	1.26	0.93, 1.71	0.138	1.42	1.18, 1.72	<0.001	1.67	1.15, 2.44	0.008
	Air hammer	645	0.88	1.55	1.23, 1.96	<0.001	1.29	1.07, 1.55	0.008	1.53	1.07, 2.18	0.020
	Hammer drill	731	0.84	1.32	1.01, 1.72	0.046	1.29	1.06, 1.57	0.010	1.40	0.92, 2.12	0.116
	Rock drill	328	0.37	1.50	1.01, 2.22	0.045	1.49	1.15, 1.94	0.003	1.72	1.02, 2.89	0.040
	Concrete vibrator	395	0.34	1.24	0.74, 2.07	0.408	1.57	1.17, 2.11	0.003	1.64	0.85, 3.13	0.138
	Asphalt tamper	336	0.31	1.16	0.66, 2.02	0.615	1.39	0.99, 1.97	0.060	1.66	0.85, 3.24	0.142
	Nail gun	258	0.29	0.80	0.41, 1.56	0.512	1.15	0.80, 1.65	0.451	0.86	0.32, 2.34	0.773
	Rivet buster	214	0.23	1.38	0.92, 2.08	0.118	1.44	1.10, 1.90	0.009	1.99	1.25, 3.17	0.004
	Nut splitter	176	0.21	1.71	1.02, 2.85	0.040	1.39	0.93, 2.07	0.107	1.37	0.57, 3.32	0.484
	Scabbler	55	0.06	1.59	0.62, 4.06	0.335	1.28	0.60, 2.75	0.522	2.15	0.66, 6.99	0.202

Among the 3,907 active male participants ≤75 yr old, due to missing information among regression covariates, exposure and health data, only between 2,655 to 2,787 participants were included in each of these regression analyses.

The frequency of daily use at work of a given tool was recorded as "Always", "Often", "Sometimes", "Rarely", or "Never", amongst participants who indicated that they had utilized said tool at some point during their employment for the railroad. These frequency categories were assigned the respective weights of 1.00, 0.75, 0.50, 0.25, and 0.00, and multiplied by the number of years participants utilized a given tool, to acquire a quantifiable measure of effective tool use. The tools are ranked in the table, according to this measure.

Tools where a majority of participants (>50%) indicated that they "Always" or "Often" use it daily at work, are listed in capital letters.

MoW: maintenance of way; BMWED: Brotherhood of Maintenance of Way Employees; n: number of participants among the 3,907 who had any exposure associated with the given tool; N: number of participants for regressions within a given outcome; PR: prevalence ratio; CI: confidence interval; *p*: *p*-value.

Table 5. The association between resultant bother from hand tool vibration and MoW workers with reported neuro-musculoskeletal diagnoses (specifically CTS and VWF) (men n=2,748)

Diagnosis of Carpal Tunnel Syndrome(CTS)	CTS %[a]	Prevalence ratio[a]
-bothered by hand tool for:		
8–10 h/d	15.00%	**8.96*** **
4–6 h/d	11.00%	**6.44*** **
1–2 h/d	7.00%	**4.22*** **
<1 h/d	3.00%	2.01
0 h (ref.)	2.00%	1
Diagnosis of Vibration White Finger Syndrome(VWF)	VWF %[a]	Prevalence ratio[a]
-bothered by hand tool for:		
8–10 h/d	17.00%	**15.25*** **
4–6 h/d	10.00%	**8.96*** **
1–2 h/d	4.00%	**3.95** **
<1 h/d	2.00%	1.62
0 h (ref.)	1.00%	1

[a]Prevalence ratio (PR) and symptom% adjusted for age, region, race/ethnicity, second job, second job vehicle vibration, spare time vehicle vibration using Poisson regression. Significant PR >2 in boldface.

MoW: maintenance of way.

**p*<0.05, ***p*<0.01, ****p*<0.001.

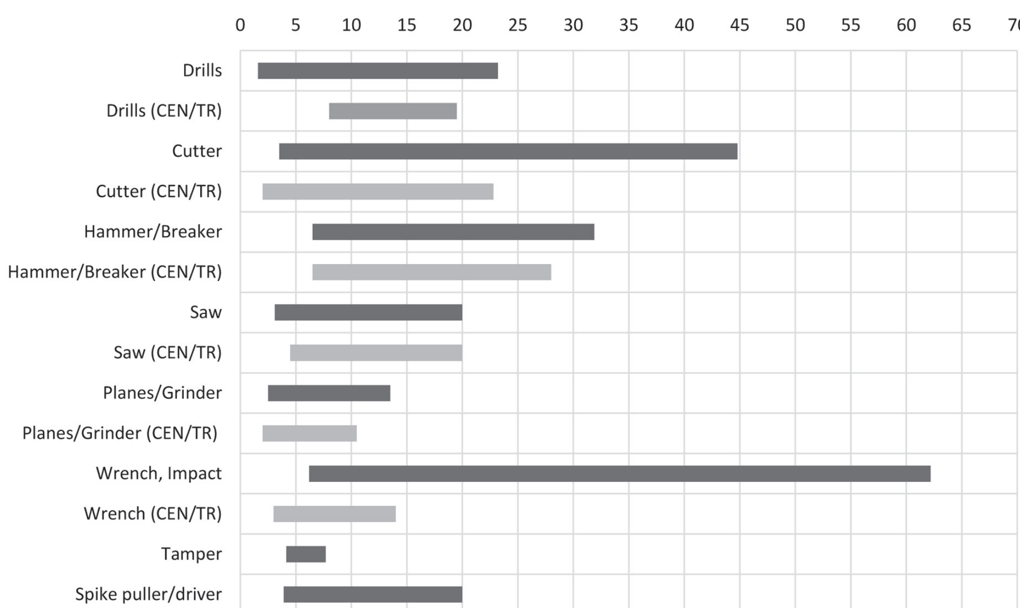

Fig. 1. Vibration emission ranges (a = m/s^2) for MoW powered-hand tools listed by manufacturer/seller and comparison of vibration magnitudes of common tools that create risk from European Union market tool categories (*CEN/TR 1030 − 2:2016, Christ *et al.,* 2010).

Table 6. Comparison of online provided vibration emission information in the North American and European markets of typical powered-hand tools used by MoW workers

	Function	Manufacturer	Power	Emission data US	Emission data EU	Emission range EU*	Weight kg	Vibration m/s^2	Uncertainty factor K	Norm	Source
	Drill					8−19.5					
1	Rock drills	AtlasCopco	Air	yes	yes		18.9	23.2	n/d	ISO 20643	RH 571-5L
2	Rock drills	AtlasCopco	Air	yes	yes		24	21.1	n/d	ISO 20643	AC 658 Series”
3	Rock drills	Airrex	Air	n/d	n/d		26.7	n/d	n/d	n/d	airrex S55 Panther
4	Hammer drill	Hilti	electric	yes	yes		3.5	11	n/d	EN 60745-2-6	TE 7
5	Hammer drill	Hilti	electric	yes	yes		9.5	7.5	n/d	EN 60745-2-6	TE 80 ATC/AVR
6	Hammer drill	Wacker Neuson	electric	yes	n/d		10	9.8	1.5	EN 61140	EH9 BL Magic
	Drill					1.5−10.5					
7	Drill	Matweld/Railtech	hydraulic	n/d	n/d		28.6	n/d	n/d	n/d	Rail drill 01500
8	Drill	Black Decker	electric	n/d	yes		1.6	10.7	1.5	EN 60745	BD HP188F3 Type 1
9	Drill	Bosch	electric	n/d	yes		2.6	16	1.5	n/d	GBH 18V EC
10	Drill	Cembre	gasoline	n/d	n/d		18.8	2.9	n/d	n/d	LD-41PY
11	Drill	Makita	electric	n/d	yes		1.7	10	2.5	EN60745	DHP453
12	Drill	Cembre	electric	yes	yes		17.3	7.06	n/d	EN 25349/28662	SD15PR-ECO
13	Drill, tie	Racine	hydraulic	n/d	n/d		14.9	n/d	n/d	n/d	Tie drill 910157
	Cutter					3−22.8					
14	Scabbler	Chicago Pneumatic	Air	yes	yes		5.5	23.1	n/d	ISO 20643	CP 0066 NS
15	Scabbler	Chicago Pneumatic	Air	yes	yes		19	44.8	n/d	ISO 20643	CP0004
16	Scabbler	Airrex	Air	n/d	n/d		3.8	n/d	n/d	n/d	Tri-Tip
17	Scaler	Hilti	electric	yes	yes		3.5	13.5	n/d	EN 60745-2-6	TE104 TE300
18	Clipping machine	Robel	gasoline	n/d	n/d		46	n/d	n/d	n/d	clipping 34.01
19	Nut splitter	ENERPAC	hydraulic	n/d	n/d		38.5	n/d	n/d	n/d	NS7080
	Hammer/Breaker					6.5−20.8					
20	Jack hammers	Chicago Pneumatic	Air	yes	yes		27.5	29	n/d	ISO 20643	0069series
21	Jack hammers	Bosch	electric	n/d	yes		29	8.5	1.5	EN60745-2-6	GSH 27 VC
22	Jack hammers	AtlasCopco	Air	yes	yes		15.5	15.2	2	ISO 28927-10	TEX 140PS:
23	Breakers	AtlasCopco	hydraulic	yes	yes		28	4.6	n/d	ISO 20643	LH 230 E”
24	Breakers	DeWalt	electric	yes	yes		18.4	6.8	n/d	n/d	D25960K
25	Breakers	Hilti	electric	yes	yes		30	7	n/d	EN 60745-2-6	TE 300AVR
	Air hammer					2.5−28					
26	Air hammer	Chicago Pneumatic	Air	yes	yes		14.5	30.1	3.6	ISO 20643	CP0125 SVR
27	Air hammer	Ingersoll Rand	Air	n/d	yes		n/d	14.8	2.2	ISO 28927	IR 115 GQC
28	Air hammer	Stanley	Air	yes	n/d		7.3	19.4	3.4	ISO 28927-10	CH15
29	Air hammer	Stanley	Air	yes	n/d		7.3	31.9	4.4	ISO 28927-10-2011	CH15
30	Air hammer	Sullair / Hitachi	Air	n/d	n/d		7.2	n/d	n/d	n/d	MCH 3
31	Air hammer	Gardner Denver	Air	n/d	n/d		15	n/d	n/d	n/d	gd 33-1
	Fastening					4.5−12.0					
32	Nail gun	Ramset	electric	n/d	n/d		1−4.5	n/d	n/d		Ramset
	Riveting					3−15					
33	Rivet buster	Chicago Pneumatic	Air	yes	yes		15.5	14.3	n/d	ISO 28927	CP 4611
34	Rivet buster	Ingersoll Rand	Air	yes	n/d		n/d	12	n/d	ISO 28927	IR Rivet Buster 9001
	Saws					4.5−20					
35	Saw	Stanley	hydraulic	yes	yes		25	13	1.9	ISO 28927-8	RS25
36	Saw rail	Geismar	gasoline	yes	yes		17.6	6.2	n/d	n/d	MTZ 400
37	Saw rail	Cembre	gasoline	n/d	yes		17.9	11.42	n/d	2006/42/EC, annex 1, 2.2.1.1	RDS-20P
38	Saw rail	Racine	gasoline	n/d	n/d		25.6	n/d	n/d	n/d	Ultra Kut III Saw
39	Saw rail	Matweld/Railtech	hydraulic	n/d	n/d		17	n/d	n/d	n/d	Saw 03900A
	Chain saw					4.5−9					
40	Chain saw	Stanley	hydraulic	yes	yes		2.8	3.1	n/d	n/d	CS05
41	Chain saw	Stihl	gasoline	n/d	yes		5.9	5.7	n/d	ISO 7505	MS290
43	Chain saw	Husqvarna	gasoline	yes	yes		6.4	8	1	ISO 22867	365Xtorq
	Reciprocating saw					11.5−20					
44	Reciprocating saw	Bosch	electric	n/d	yes		3.6	19.5	1.5	EN 62841-2-11:	GSA 1100 E Prof.
45	Reciprocating saw	Hilti	electric	yes	yes		4.8	20	n/d	EN 60745-2-11	WSR1400
46	Reciprocating saw	DeWalt	electric	n/d	yes		1.4	9	1.5	n/d	DCS310

	Function	Manufacturer	Power	Emission data US	Emission data EU	Emission range EU*	Weight kg	Vibration m/s^2	Uncertainty factor K	Norm	Source
	Grinder					2−10.5					
47	Grinder	Stanley	hydraulic	n/d	n/d		9.2	n/d	n/d	n/d	GR60
48	Grinder, bullnose	Stanley	hydraulic	n/d	n/d		5.2	n/d	n/d	n/d	HG60
49	Grinder, profile	Stanley	hydraulic	yes	yes		53.5	3.4	1	ISO 8662-3; 5349-1.2	PG10
50	Grinder, frog	Matweld/Railtech	hydraulic	n/d	n/d		55.5	2.5	n/d	n/d	09200A
51	Grinder	Geismar	gasoline	n/d	n/d		70	8.79	n/d	n/d	MP12
52	Grinder	Racine	hydraulic	n/d	n/d		4.5	n/d	n/d	n/d	910113
53	Grinder	Makita	electric	n/d	yes		2.3	13.5		n/d	GA5021
	Screwdriver/Wrench					3−14					
54	Impact wrench	Stanley	hydraulic	yes	n/d		12	49	5.2	EN 12096	IW16 (2015 Manual)
55	Impact wrench	Stanley	hydraulic	yes	n/d		12	62.2	13	ISO 28927-2	IW16 (2019 Manual)
56	Impact wrench	Matweld/Railtech	hydraulic	n/d	n/d		15	n/d	n/d		Impact Wrench 1” 01600A
57	Impact wrench	Bance	gasoline	n/d	n/d		19.5	19	n/d	n/d	GT350
58	Impact wrench	Cembre	electric	yes	n/d		19	8.68	n/d	ENV 25349 EN 28662	NR11P
59	Impact wrench	Racine	hydraulic	yes	n/d		12	49.7	n/d	n/d	Model 910193
60	Wrench	Robel	gasoline	n/d	n/d		88–100	6.2	n/d	n/d	power wrench 30.82
	Rail tool										
61	Tamper	Stanley	hydraulic	yes	yes		25	7.7	1.3	n/d	TaT
62	Tamper	Matweld/Railtech	hydraulic	n/d	n/d		28.1	n/d	n/d	n/d	8200 Tamper
63	Tamper	Robel	gasoline	n/d	n/d		24.4	5.7	n/d	n/d	62.05
64	Tamping machine	Geismar	gasoline	n/d	n/d		34	4.14	n/d	n/d	TT-2E
65	Spike puller	Stanley	hydraulic	n/d	n/d		22	n/d	n/d	n/d	SPL31
66	Spike puller	Matweld/Railtech	Air	n/d	n/d		24.5	n/d	n/d	n/d	spike puller 1100
67	Spike puller	Geismar	gasoline	n/d	n/d		82	3.91	n/d	n/d	AC1
68	Spike puller	Geismar	gasoline	n/d	n/d		130	n/d	n/d	n/d	AS3
69	Spike puller	Racine	hydraulic	n/d	n/d		22.2	n/d	n/d	n/d	Model 910097
70	Spike puller	Stanley	hydraulic	n/d	n/d		22	n/d	n/d	n/d	SP48
71	Spike driver	Stanley	hydraulic	yes	n/d		30	20	n/d	n/d	Stanley SD67
72	Spike driver	Matweld/Railtech	hydraulic	n/d	n/d		29.5	n/d	n/d	n/d	spike driver 8300
73	Spike driver	Geismar	hydraulic	n/d	n/d		n/d	n/d	n/d	n/d	SD-2E
74	Spike driver	Geismar	hydraulic	n/d	n/d		n/d	n/d	n/d	n/d	SD-1
75	Concrete vibrator	Chicago Pneumatic	air	n/d	n/d		19	n/d	n/d	n/d	CP2190

*Source: (CEN) ECFS. Hand-arm vibration Guidelines for vibration hazards reduction-Part 2: Management measures at the workplace. CEN/TR 1030-2. Brussels, Belgium: CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels; 2016.
Listing of manufacturer(s) or specific tool(s) are for illustrative purpose only and does not mean any endorsement or guarantee of performance by the authors and may not be representative of your experience.
MoW: maintenance of way.

The purchasers and users of powered-hand tools (such as breakers, tamping guns, spiking guns, rail drills, grinders, spike pullers/drivers, tampers and saws) in the NA market would have no easy access to important vibration emission information and data. The majority of the tool technical information, specification sheets and descriptions in the NA market mentioned no vibration emission information at all on the corporation web sites, online catalogues or in the downloadable manuals (58%). Also, in the NA market, only 42% of the selected hand-tools had specific vibration information listed by the manufacturers (mostly international corporations based in the EU). Furthermore, an examination and comparison of the available tool emission listings is complicated, because manufacturers often used different standard references (n=20) (for example, European Standards [EN/CEN] vs. International Standardization Organization [ISO] standards) for their laboratory vibration measurements of hand-tools; 55% of the NA manufacturers/sellers listed no standard reference at all.

Only few of the international corporations currently provide detailed vibration emission information in both EU and NA markets, including vibration levels (a_h), uncertainty factor (K), and/or the utilized measurement standard. The majority of the manufacturers and distributors that sell tools for either or both markets do not follow the ISO recommendations, and provide only limited-to-no vibration data. On the websites accessed in the EU market, the majority of the listings showed some or all of the required emission information, including the uncertainty factor (mentioned in 75% of checked listings) and the measurement standard that was utilized (mentioned in 55% of the checked listings).

Of all of the powered-hand tools used by this trade 88% of the selected tools exceeded a=5 m/s^2 and was above vibration magnitudes of common tools of other comparable industries. This may create a risk if these tools are used throughout an 8-h work day and management of vibration exposure is needed. The highest vibration emission value listed in a user manual was by a manufacturer of an impact wrench, which was recorded at an exceptionally high 62.2 m/s^2 (Table 6, Fig. 1). The majority of the powered-hand tools used by MoW exceeded the vibration emission range, and highest levels compared to the general construction or other industry reference ranges for tools measured by independent organizations in the EU (see also the EU HAV guidelines and others for similar tool categories) (Fig. 1)[12, 24, 25], although one would have to factor in the actual exposure duration in an typical 8-h work day.

The mean weight of the powered-hand tools was 20.8 kg, and the median was 17.7 kg (range 1.4 to 130 kg). The majority of specific tools used by MoW-workers, such as spike drivers, spike pullers and tamping equipment, had no vibration emission listed by the NA manufacturer or sellers. Based on our survey, in particular, impact wrenches, cutters, hammer/breakers and saws that were listed with high vibration emissions had significant associations with reported disorders of the hand and wrist, CTS or White-Finger symptoms among MoW workers (Tables 3 and 4).

Discussion

This study examined the musculoskeletal and neurological complaints of maintenance-of-way railroad workers, and their possible relationship to the use of trade-specific powered-hand tools. In occupational health, a causation analysis and risk assessment are based on establishing a proper diagnosis, the employee's personal work history and a definable exposure to a known occupational risk factor (for example, non-neutral wrist posture, repetition, physical factors (vibration)); preferably it includes an individual daily vibration exposure A (8) analysis based on the contribution of all tools used throughout a shift, as well as documentation of the scientifically supported probability of a causal link. Guidance of a hand vibration related exposure action value (EAV) and exposure limit value (ELV) (2.5 m/s^2 and 5.0 ms^2, respectively) for the use of a tool in a typical 8-h work shift are published in the EU Directive 2002/44/EC[12] and are repeated in the U.S. ANSI S2.70 standard[26]. However, in the US no enforceable standard exist that would regulate work place monitoring and risk surveillance. A specific categorical recognition as an 'occupational disease' of HTV does not exist in North America; although the Federal OSHA 'General Duty Clause' would apply mandating employment free from recognized hazards (29 U.S.C.§ 654, 5(a)).

We found that MoW workers who reported a high rate of shoulder, elbow and hand/wrist pain also reported to work frequently with powered-hand tools that are listed with the highest vibration emissions by the manufacturer and other independent resources. Nevertheless, the actual frequency- and time-weighted A (8) values pertaining to a worker's individual daily HTV exposure, may be a combination of different tools with dissimilar emission levels used throughout the work shift. Occasional exposure to vibration is likely to present a different risk than exposure every day and for prolonged periods. For a worker with multiple HTV exposures during a shift, those exposures must be added together to determine the worker's actual cumulative A (8) exposure value, which may be then compared to the EU/ANSI action value (EAV) and exposure limit value (ELV)[27, 28]. Actual daily 8-h exposure maybe within the EU guidelines for an individual worker, if specific tools even with high emissions are used sparingly. In addition, it should be noted that the standardized laboratory-based emission tests reported by manufacturers are primarily intended for assessing the vibration emissions of powered hand tools and tool comparisons under typical working conditions. Nonetheless, this information may be also useful for a risk assessment and for intervention strategies by selections of tools with lower vibration emissions.

Occupational health specialists depend on multiple sources of information or data, and have to confront limited and missing information. Workers with occupational HAV or HTV exposure may report a variety of non-specific health complaints. Occupational health and safety providers frequently may not recognize such occupational disorders, and may be unfamiliar with vibration emissions information or proper exposure assessment guidelines, therefore miss timely intervention and prevention opportunities.

It is established that prolonged and increasing vibration exposures among powered-hand tool operators can lead to irreversible musculoskeletal, vascular and nervous system disorders of the upper extremity. Exposure reduction through administrative or technical controls can minimize and prevent such risks caused by HTV[29–31]. Although there may be unique differences and clinical presentations in diverse environments (temperature/humidity) and countries, national legislation for controlling of occupational vibration exposure appears to be nevertheless beneficial to reduce exposure[32].

As a recent study has shown, in addition to vibration emission, the grip forces necessary to hold and guide the tools (determined by the handle design and tool weight) and repetitive movements are factors related to nerve damage[33]. Tool design and handle location may lead to non-neutral postures and aggravate physical factors[34]. An updated epidemiological validation for a supplementary method to study vascular disorders from hand-transmitted vibration has been recently discussed[35].

This is the first known study of its kind. No similar studies of railroad workers are available for direct comparison. Pertaining to health disorders, MoW-workers appear to have a high risk of chronic pain sensation in the hands, wrists, elbows and shoulders, carpal tunnel syndrome (CTS), and symptoms consistent with vibration-related disease (i.e., fingers blanching with clearly demarcated areas) or neurological disorders (i.e., difficulties with picking up very small objects, such as screws or buttons, or opening tight jars). Additionally, the analysis of the tool vibration emissions showed that powered-hand tools typically used by MoW-workers have greater and higher vibration ranges compared to tools used in other industries (such as construction and metal working) and therefore, different intervention strategies should be considered. It is known that the life-time vibration dose in workers using different tools was a good quantitative exposure assessment, and correlated with symptoms when adjusted for confounding factors[36].

In addition to administrative controls (i.e., time management), vibration risk can be controlled with the use of tools and equipment that incorporate vibration attenuation technology and improved design[37]. Key for effective work site control would be reliable and easily comparable emission data and information for the employer, buyer and user. According to the EU directive and ISO/ANSI standards, the responsibility for limiting occupational HTV exposures lies with the employer, and employers are instructed to give priority to reducing HTV at the source. In order to compare tool models based on their vibration emissions, the tools must be assessed under comparable operating conditions and in representative work tasks for which they are intended to be used. In order to standardize such tool assessments, the ISO and other organizations have several laboratory-based testing standards for comparing tools, according to their tool handle vibration emissions (Table 6, Norms). These standards typically prescribe the postures, applied hand forces, and loading conditions under which the tools will be evaluated.

This study showed that employers and occupational health provider in the North-American market have great difficulties identifying tool emissions and are at a disadvantage compared to the EU, where such vibration published information is mandated. Many NA manufacturers, distributors and suppliers provide limited-to-no vibration information, or it may be very difficult to find these online resources. Furthermore, independent studies have shown that standardized laboratory measurements from the manufacturer may differ considerably from "real life" measurements, due to usage and handling differences, maintenance issues and the age of tools[38].

Knowledge of site-specific usage of tools, practical user issues and an occupational history, are all key to risk management, in addition to manufacturer emission data[38, 39]. In an earlier European comparative study of the mandated vibration information provided by manufacturers in sales brochures and operating manuals, deficits and omissions have been noted as well, as not every company in the EU provided all of the necessary details of vibration emission levels, un-certainty factor K, and the applicable laboratory measurement standard[40]. Therefore, workplace measurements following national or international guidelines (e.g., ISO 5349 part 1 and 2[28, 41]) or ASA 2006[42]) may be indicated in cases of insufficient or conflicting vibration emission information. Guidance in the "good practice on hand-arm vibration" has been established by the European Commission and the EU committee for standardization and includes a risk identification procedure, determination of the exposure duration, vibration magnitude and other information source (such as data banks with "real use" measurements)[12, 24]. Further guidance for HAV is also provided in the US by ACGIH[43] and the US General Service Administration (GSA)[44]. The choice of alternative tools with improved vibration attenuation and engineering design can lead to considerable vibration exposure reduction. In the USA, a government-industry consensus standard for the requirements and technical guidance for the procurement, maintenance and use of hand-held powered tools is available[45]. The lack of enforceable standards in the US for the measurement and control of HTV exposures in the workplace is an obstacle to introduce modern vibration attenuation tools compared to the EU, Japan and other countries.

One limitation of the current study is the apparent low participation rate of MoW workers, which may be explained, in part, by their demanding work schedules, the many detailed survey questions, general “survey fatigue” by people in the US and limited internet access due to work related travel. This response rate raises the potential of selection bias, or the possibility that people who answered the survey were not representative of all BMWED members. However, our phone survey of non-respondents indicated that respondents to the major survey were in better health (with the exception of back pain) and had slightly better working conditions than members who did not fill out the major survey. This suggests that our current analysis may underestimate the associations between working conditions and musculoskeletal symptoms among MoW workers.

Our cross-sectional study design and the lack of direct measurements of vibration exposures under field conditions limits our ability to draw firm conclusions about causality, since exposures and outcomes were assessed at the same time. And self-report of exposures and outcomes may increase the possibility of information bias, although it has been suggested that due to the better pay-scale, fear of job loss or other disciplinary action, underreporting of injuries is more likely. However, associations between our study’s work factors and health outcomes have been shown to be causally related in prospective studies[33, 46)]. Still, access to anonymous medical claim or disability data would be useful to determine whether the current analyses could be replicated.

An exact daily vibration exposure A (8) of all the tools used by MOW could not be calculated, as the magnitude of actual vibrations in the field and duration of exposure times (h) are not known for each survey participants. Yet, the likely contribution of different tool types and sources can be estimated by the review and comparison of the emission data and a precise work history. In most cases workers use a combination of tools and then the partial vibration exposures from each tool are calculated from the magnitude and duration for each source. During 8 h working, the actual tool operation time of a worker could be less than one 1 h. Then, the A (8) could be less than 2.5 m/s^2, even if the tool vibration emission value could be more than 10 m/s^2. The overall daily vibration exposure can be calculated from the partial vibration exposure values for each tool used by the worker:

$$A\left(8\right) = \sqrt{A^2(8)(\text{tool a}) + A^2(8)(\text{tool b}) + A^2(8)(\text{tool c}) + \ldots}$$

In future research, medical monitoring of MoW workers, field ergonomic and vibration assessments, as well as intervention studies utilizing tools with modern vibration attenuation/dampening designs, would be beneficial. Short of conducting one’s own vibration measurements, tool vibration emission data from independent databases are available online in the USA (limited database)[47)], Germany[48, 49)], Italy[50)], Sweden[51)] and specifically for railroad tools in the UK[52)] that may be useful for a preliminary risk assessment and consideration of alternatives.

In conclusion, the comprehensive health survey suggests that MoW workers have a high risk of typical hand-transmitted vibration-related disorders. The increasing use of special powered-hand tools with high vibration emission profiles used by this trade is particularly bothersome in workers with known disorders of their hand/wrist. In the North-American market, little-to-no vibration emission data from manufacturers is readily available for users or occupational health providers, which impedes medical monitoring and the selection of alternative tools with better vibration suspension technology. A comparison of vibration emission information of powered-hand tools typically used by MoW workers showed that under EU regulations, medical monitoring and interventions of MoW workers would be necessary and beneficial. Additional field measurements and research would provide more information about specific tool design, non-neutral postures, physical hazards, alternatives and vibration attenuation effects through technological improvements and interventions. Details of vibration information (vibration emission levels m/s^2, uncertainty factor K, and the applied testing standard) can assist employers, users and occupational health providers to better manage risk and select tools with lower emission profiles.

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