Influence of ergonomic factors on peripheral neuropathy under HAV exposure

Abstract

Background: Hand-arm vibration (HAV) is a risk factor for carpal tunnel syndrome (CTS) and ulnar neuropathy at the elbow (UNE). It is unclear how ergonomic factors influence the relationship between HAV exposure and CTS and UNE.

Aims: We aimed to assess the relationship between cumulative HAV-exposure and CTS and UNE in workers exposed to HAV from two tools with different ergonomic profiles.

Methods: We performed nerve conduction studies (NCS) of the sensory and motor median and ulnar nerves and recorded symptoms indicating CTS and UNE in workers exposed to HAV from impact wrenches or from rock drills. Exposure was measured as cumulative life-time exposure. We used linear regression adjusted for age and BMI to assess linear relationships.

Results: 65 workers participated (33 rock drill and 32 impact wrench operators). We found inverse linear associations between cumulative HAV exposure and median nerve sensory conduction velocity in impact wrench operators and ulnar nerve motor conduction velocity in rock drill operators (beta of 0.63 and 0.75). Based on NCS findings and symptoms, 7 impact wrench operators had CTS and 1 UNE, and 4 rock drill operators had CTS and 6 UNE.

Conclusions: Our findings indicate that ergonomic factors influence the development of CTS and UNE under HAV exposure. The ergonomic profile seems to influence which type of neuropathy workers exposed to HAV will develop. Design of occupational exposure guidelines and future studies should

be based on ergonomic profile and exposure characteristics for different tools and not merely hand-arm vibration.

Introduction

Occupational exposure to hand-arm vibration (HAV) is very common and may be a cause of carpal tunnel syndrome (CTS), and other localized neuropathies, e.g. of the ulnar nerve at the elbow (UNE) and neurological hand-arm vibration syndrome (HAVS) (1). However, how these diseases relate to the combination of vibration exposure and ergonomic factors is unknown.

Ergonomic risk factors for CTS and UNE, such as repetitive, forceful movements and static loading of the wrist and elbow (2, 3) are omnipresent in jobs containing HAV exposure. In addition, vibrating tools may be used predominantly as hand guided tools, e.g. rock drills, with the hands guiding the tool rather than clenching firmly or as handheld tools with the hands clenching firmly, e.g. impact wrenches. The effects are often impossible to separate from the effects of HAV exposure (4). Depending on the ergonomic profile of the work, some ergonomic factors might enhance the effect of HAV exposure and others mitigate it. However, literature often focusses on the isolated role of HAV exposure for the development of CTS and UNE instead of the ergonomic profile of the jobs. This might not reflect the complexity of the interaction of risk factors (4). It is for example unclear if different ergonomic profiles such as predominantly working with hand guided or handheld vibrating tools leads to injury of different fibres.

To complicate matters more, studies on the relation between exposure and neuropathies have not used the same diagnostic criteria. Some studies have used clinical criteria alone (3, 5) without nerve conduction studies (NCS). Unfortunately, it may be difficult to differentiate neurological HAVS and CTS based on clinical criteria alone (6, 7). Instead, the combination of clinical criteria and standardized NCS is recommended for diagnosis of CTS and UNE (8, 9) as this enhances sensitivity and specificity. Thus, investigating neuropathy in the median and ulnar nerves using both standardized clinical and internationally established NCS criteria is essential.

We aimed to assess the putative association between CTS, UNE and work with vibrating tools in two groups of workers with different ergonomic profiles. Therefore, we assessed presence and degree of neuropathy using a combined clinical and neurophysiological approach in workers using rock drills (a hand guided tool) and impact wrenches (a handheld tool).

Methods

We designed a cross-sectional study and recruited the study sample in the context of a Norwegian occupational health survey among Norwegian road workers. Ethical approval was provided by the regional authority (Regional Ethics Committee, REK 2013/1031). Data were collected in 2015 and 2016. Informed written consent was supplied by all workers.

Assessment of vibration exposure was done as described previously (10). In short, we calculated vibration exposure using average exposure time and averaged vibration exposure of the two main tools. To assess exposure time, we interviewed workers and measured exposure times in the field. We measured vibration exposure using Larson Davis HVM100 (Larson Davis, Depew, NY, USA) and Svantek SV106 (Svantek, Warszawa, Poland) vibration meters in accordance to ISO 5349 part 1 and part 2 (11). Our estimate of cumulative lifetime exposure was based on sets of questions as suggested by the VIBRISKS protocol (12) and information about previous and current application of tools emitting hand-arm vibration other than the two main tools during work and spare time. Exposure estimates were refined using company work records.

To assess nerve dysfunction, nerve conduction studies (NCS) were used. In NCS, peripheral nerves are depolarized through electrical stimuli. The resulting nerve and muscle responses measured by recording electrodes are objective measures of nerve function, allowing subtyping and categorizing findings into e.g. demyelinating and axonal pathologies. NCS is able to assess severity of disease processes, which is particularly useful for clinical entities like CTS and ulnar neuropathy (13).

Nerve conduction studies (NCS) were performed as described previously (14, 15) on a portable Natus Key point EMG (Alpine Bio Med, Denmark), assessing sensory and motor fibres of the median and ulnar nerves of both arms. For recording, we used surface electrodes (Alpine biomed, Skovlunde, Denmark) and stimulated using a handheld stimulation bar. The same types of stimulation and recording electrodes were used for motor and sensory NCS. To ensure hand surface temperature at 30 degrees Celsius, temperature was measured using a handheld infrared thermographic scanner (Exergen Corporation, Watertown, MA, USA) and hands were heated in warm water. We used supramaximal stimulation. Amplitude height was defined by the distance between the baseline and the negative peak (motor) or by the intersection between the negative peak and a line between the first and the last negative peak (sensory). Latencies were measured as onset (motor) or peak (sensory). We stimulated the motor ulnar nerve at the wrist, 10 cm proximal to and 3 cm distal to the medial epicondyle and the median nerve at the fossa cubiti and distally at the wrist. We performed orthodromic sensory NCS of the palmar branch, the 2nd, 3rd, 4th finger (median nerve) and of the palmar branch, the 4th and 5th finger (ulnar nerve). We executed motor NCS of the 2nd lumbrical muscle and the first interosseal muscle as described by Preston and Logigian (16) as a median to ulnar nerve latency comparison test.

All NCS data was transformed into Z-scores, i.e. deviance between the measured value in standard deviations (SD) from the age and height corrected reference mean value (17). We used normal values obtained from a multicentre Scandinavian effort integrated in our software (PowerPack, Stefan Stålberg Software). Amplitudes which were non-recordable for technical reasons were set as missing, absent responses were set as 0 µV, resulting in a high Z-score. Signs of the Z-scores were adjusted so that a high positive value (≥ 2SD) is considered pathological.

CTS was defined as the combination of NCS findings indicative of median nerve entrapment at the wrist (MNW) and the presence of predefined symptoms (15). MNW was defined according to Padua grading scale (14, 18) (Table 1)**.** Two of these symptoms had to be present: episodes with a tingling or numb sensation in the radial four fingers at night , and symptom reduction upon flicking the arm. One of these symptoms could be substituted if either first degree relatives had CTS or if the hand felt weak. Workers who met the criteria for CTS and had additionally reduced ulnar sensory amplitudes were classified as having CTS, according to literature (19, 20).

For UNE, we required reduced (< 2SD) motor conduction velocity across the elbow and additionally the presence of numbness or paraesthesia in the hand outside of the median nerve distribution or weakness in the hand. Reduced ulnar nerve digital sensory amplitudes (< 2SD) were regarded as non-localizing finding indicative of ulnar neuropathy (21).

We used Z-scores of NCS data as outcome variables in the regression analysis. We selected combined Z-scores (cZ-score) (22) based on neurophysiological properties of neuropathy (9, 18). For CTS, we averaged the Z-scores of median nerve sensory conduction velocity in the 2nd- 4th finger. Other neuropathy in the median nerve consistent with HAVS was considered by using the Z-score of the distal motor latency of the median nerve and by the cZ-scores of the median nerve sensory amplitudes in the 2nd- 4th finger. (1) UNE was considered by the Z-score of the ulnar motor conduction velocity across the elbow and by the cZ-score of the sensory amplitudes of the ulnar nerve measured at fingers 4-5.

We performed adjusted linear regression analysis to assess associations between cumulative HAV exposure and nerve dysfunction as measured by NCS. We decided a priori to include age and BMI as covariates, as they might potentially be confounding factors (8). We tested whether the necessary assumptions held true by visually assessing linearity between cZ-scores and the covariates using scatterplots with superimposed regression lines, assessing multicollinearity by variance inflation factor (VIF) and assessing homoscedasticity and normality of the residuals.

As this was an exploratory study and not a confirmatory analysis, we did not adjust for multiple testing (23). All analyses were performed with SPSS V.24 (IBM SPSS).

Results

All invited workers participated. Out of 77 workers, 12 had either no exposure to HAV (N= 5) or not technically satisfying NCS data (N=7). The remaining 65 were included in further analysis. Thirty-three workers were exposed to rock drills as their main tool and 32 to impact wrenches as their main tool. Among the rock drill operators, 11 declared additional use of impact wrenches. One of the impact wrench operators used additionally rock drills. The group of rock drill operators had a mean BMI that was 3.0 kg/ m^2 lower than that of the impact wrench users and were on average 7 years younger. The mean cumulative HAV exposure was 13650 units higher for rock drill operators. Details about the study population are presented in Table 2. Workers were exposed to HAV from two tools: rock drills and impact wrenches. Rock drills are typically hand guided tools with their weight supported by the drill rod when used vertically and by a suspension system when used horizontally. Impact wrenches are typically hand-held tools as they rest in the hand of the operator.

Exposure time was estimated as 47 min/ workday for rock drill operators and 15 min/ workday for impact wrench operators. We assigned the rock drill operators an exposure to root mean square (rms) vibration of 17 m/s^2 during active operation and the impact wrench operators an exposure to rms vibration of 7 m/s^2, corresponding to average daily exposure levels of 5.4 m/s^2 (A8) and 1.2 m/s^2 (A8), respectively.

Based on NCS findings and clinical symptoms, eleven workers were diagnosed with CTS (seven impact wrench and four rock drill operators, respectively) and seven workers were diagnosed with UNE (one impact wrench operator and six rock drill operators, respectively). One rock drill operator and one impact wrench operator had NCS findings consistent with median entrapment at the wrist (MNW), but had no symptoms. Two workers had NCS findings consistent with HAVS (isolated increased distal motor latency), but no symptoms. All other workers with increased distal motor latency had additionally reduced sensory conduction velocity and could be classified as CTS or MNW. Four workers had CTS and had additionally reduced sensory amplitudes in the ulnar nerve. Details about NCS results and neuropathies are presented in tables 3 and 4, respectively.

We found a significant association between cumulative HAV-exposure and median nerve sensory CV in the group of impact wrench operators. In the group of rock drill operators, a significant association between cumulative HAV-exposure and ulnar nerve motor CV across the elbow was found. Neither of these associations could be identified in the other group. There was no significant linear association between exposure and the other outcome variables (Table 5).

Discussion

Working with vibrating tools was associated with CTS and UNE. However, the strength of the associations and the neuropathic patterns were different for impact wrenches than for rock drills. CTS was the dominating neuropathy resulting from exposure to impact wrenches, and UNE the dominating neuropathy resulting from exposure to rock drills.

In workers exposed to impact wrenches, the sensory conduction velocity of the median nerve decreased by 0.63 SD for every unit of HAV exposure, expressed as log10 m/s^2 times hours (h). Reduced sensory CV in the median nerve is a hallmark NCS parameter for CTS and precedes additional development of pathological distal motor latency and sensory amplitudes in more severe CTS (18). Accordingly, CTS (defined as presence of typical symptoms and NCS criteria met) was the dominating neuropathy among impact wrench operators and with a prevalence higher than in other groups of workers (3).

In contrast, working with rock-drills was associated with a reduction of the ulnar nerve motor CV in the elbow by 0.75 SD for every increase in units of exposure. Accordingly, the prevalence of UNE in this group was relatively high (5). UNE in workers has received little attention despite extensive symptoms and functional impairments in the hands (24). Our findings indicate that UNE in workers exposed to HAV might have a higher prevalence than previously assumed and deserves more attention (5).

We argue that the different neuropathic patterns in the two exposure groups could reflect the influence of tool specific ergonomic factors. The impact wrench is a handheld tool requiring stabilization in a horizontal plane, leading to a high transmission of vibration to the wrist (25) and the carpal tunnel. Moreover, its operation requires a firm grip, which in itself is a risk factor for CTS (3). In addition, it allows for little variation in handling and wrist position, reducing the potential for mitigating the transmission of vibration to the hand. In contrast, rock drills are hand-guided rather than handheld, allowing for a greater variation in grip force and finger and wrist position. While still transmitting energy to the median and ulnar nerves at the wrist, this variation in handling might dilute a linear inverse relationship between HAV and nerve conduction at the wrist. The rock drill requires the worker to stabilize the tool in a vertical or horizontal axis and to hold their elbow in a relatively fixed position, both of which leads to high transmission of vibration energy towards more proximal locations such as the elbow (25). Further, the vibrations of the rock drill have very high amplitudes which are likely to be transmitted to the elbow joint. It seems plausible that these factors enhance the local effect of vibration in the elbow, which is a vulnerable location for the ulnar nerve.

The distal motor latency and sensory amplitudes of the median nerve were not significantly associated with cumulative HAV exposure. Isolated NCS pathology in these parameters is sometimes regarded as indicative of neurological HAVS (1). However, in most workers with NCS findings in our sample, these parameters were pathological only in combination with median nerve sensory conduction velocity outside of the reference range. This pattern fits well with moderate and severe CTS (18). Some workers had NCS findings consistent with CTS combined with ulnar nerve sensory amplitude reduction. Similar NCS patterns have previously been interpreted as indicative of HAVS (6). However, this pattern is common in idiopathic CTS (19), especially in patients with frequent and protracted hyperextension at the wrist (20). All workers with these NCS findings had symptoms consistent with CTS, in particular episodic symptoms during the night, which further suggests that this pattern reflects CTS (6) and not neurological HAVS.

A strength of this study is the use of established clinical and NCS criteria for CTS and UNE. The utility of NCS as a screening instrument for CTS has been questioned due to the high rate of false positive results (26). The prevalence of asymptomatic NCS findings indicating CTS was much lower in the present study than in previous reports (26, 27), which used only one comparison test of the median-ulnar sensory latency difference. In contrast, our NCS criteria are based on more severe findings, which has a better specificity (13). For example, we required at least 2 comparison tests to be positive for the mildest grade of NCS findings compatible with CTS.

It is not possible to infer causality due to the cross-sectional design. For instance, it is not possible to estimate to what degree CTS and UNE are associated with HAV exposure alone, a combination of HAV exposure and physical work, or ergonomic factors alone, e.g. repeated heavy lifting (3). However, the prevalence of CTS and UNE was higher in our sample than in manual workers not exposed to HAV (2, 3) suggesting a synergistic role of these factors and HAV exposure in HAV exposed workers (4, 28). The assessment of total lifetime HAV exposure is challenging, as certain information is difficult to collect, for instance maintenance status of previously used tools, exact values of exposure time and exposure levels, and information about the handling of tools. A major limitation is the small sample size. This has an impact on the precision of the effect estimates and resulted in large confidence intervals. It is thus difficult to appreciate the true size of the observed effect.

Lastly, a healthy worker effect might be present, leading to an underestimation of pathology.

Exposure corresponded well to typical reported levels tools (10, 29), and was, for impact wrench operators well within present daily limit and action values. However, there was a relatively high prevalence of CTS in this group. Our findings indicate that the type of vibrating tool with its specific ergonomic profile shape the relationship between HAV exposure and peripheral neuropathy. Exposure from different tools seems to put different nerves and different nerve segments at risk, something that is not reflected by the present occupational exposure guidelines. The relationship between ergonomic factors, hand-arm vibration exposure and development of peripheral neuropathy should be further assessed by longitudinal studies including different tool categories with different ergonomic factors. Further, we will advise future research studies to apply recommended standards for the detection of peripheral neuropathy using a combination of NCS and clinical assessment.

Key learning points

What is already known about this subject

- Among workers exposed to hand-arm vibration, peripheral neuropathies as carpal tunnel syndrome and ulnar neuropathy at the elbow are common.
- It is unclear if this is due to vibration exposure alone or if the ergonomic profile and type of vibrating tool influence the development of peripheral neuropathy.

What this study adds

- The ergonomic profile and type of vibrating tool seem to influence the effect of vibration exposure. How the respective vibrating tool is operated is important.
- In our sample, work with a handheld tool was associated with CTS, whereas work with a hand-guided tool was associated with UNE.

What impact this may have on practice or policy

- Our findings may raise awareness for the role of ergonomic factors in the risk assessment of workers with hand-arm vibration.
- Occupational guidelines and limit values should not be based on vibration alone but take type of tool and the associated ergonomic profiles into consideration.

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Table 1 NCS severity grades

Severity grade	NCS findings
Normal	None
Minimal	significant difference between median/ulnar sensory latency ≥0.5 ms in the fourth digit and a significant difference between motor latency in the second lumbrical muscle and the first dorsal interosseous muscle >0.8 ms
Mild	reduced (< 2SD) conduction velocity of the sensory median nerve in at least 2 fingers
Moderate	motor distal latency above the normal limit in addition to reduced sensory conduction velocity
Severe	absent median nerve sensory amplitudes (< 0.2 µV) in at least two fingers
Extreme	absence of both motor and sensory responses

Table 2 Study population

	Rock drill exposure 5.4m/s^2 (A8) right hand	**Impact wrench exposure 1.2m/s^2 (A8) right hand**
N	33	32
Age mean (SD)	39 (12)	46 (11)
BMI (SD)	25 (2)	28 (4)
Smoking/snuffing, n (%)	17 (51)	16 (50)
Height, cm (SD)	182 (5)	179 (6)
Total exposure, years (SD)	11 (12)	15 (13)
Vibration exposure level (m/s^2)	17	7
Vibration exposure (min/ day)	47	15
Vibration exposure (hour * m/s^2) mean (SD)	17100 (23700)	3450 (3270)

Table 3 Nerve Conduction Study. Selected compound Z-scores for the two exposure groups

	Rock drill exposure 5.4m/s^2 (A8) right hand	**Impact wrench exposure 1.2m/s^2 (A8) right hand**
NCS parameter	**Mean Z-score (SD)**	**Mean Z-score (SD)**
cZ-score median nerve digital sensory CV †	0.96 (0.85)	1.01 (0.91)
Z-score Median nerve distal motor latency	0.88 (0.80)	1.02 (1.35)
cZ-score median nerve sensory amplitudes ‡	0.27 (0.82)	0.44 (0.97)
Z-score ulnar nerve motor CV across the elbow	0.33 (1.12)	0.22 (1.26)
cZ-score ulnar nerve sensory amplitudes §	1.25 (0.81)	1.09 (0.86)

† cZ-score median nerve digital sensory CV= combined Z-score of the median nerve sensory conduction velocity in the second, third, and fourth fingers; ‡ cZ-score median nerve sensory amplitudes= combined Z-score of the median nerve sensory amplitudes in the second, third, and fourth fingers; § cZ-score ulnar nerve sensory amplitudes= combined Z-score of the ulnar nerve sensory amplitudes in the fourth and fifth fingers

Table 4 Distribution of neuropathy (defined as classical symptoms and NCS findings) among the two vibration exposure groups

Neuropathic pattern	Rock drill exposure 5.4m/s^2 (A8) right hand	Impact wrench exposure 1.2m/s^2 (A8) right hand
No neuropathy, n (%)	23 (69)	24 (75)
CTS, n (%)		
Minimal†	1 (3)	1 (3)
Mild‡	0	1 (3)
Moderate§	1 (6)	2 (6)
Severe¶	0	1 (3)
CTS combined with reduced ulnar nerve sensory amplitudes	2 (3)	2 (6)
Total	4 (12)	7 (21)
UNE, n (%)		
Isolated reduced (<2 SD) sensory amplitudes ulnar nerve	1 (3)	0
Reduced motor CV (<2 SD) in the elbow	2 (6)	1 (3)
Combined reduced sensory amplitudes and motor CV	3 (9)	0
Total	6 (18)	1 (3)

† Minimal CTS = difference between ulnar and median nerves sensory latency in the fourth digit >0.5 ms and difference between motor latency in the second lumbrical muscle and the first dorsal interosseous muscle >0.8 ms; ‡ mild CTS= median nerve digital sensory conduction velocity < 2SD in at least 2 fingers; § moderate CTS = mild CTS and motor distal latency > 2 SD; ¶ severe CTS = median nerve motor distal latency > 2 SD and additionally absent median nerve digital sensory amplitudes (< 0.2 µV) in at least 2 fingers.

Table 5 Linear models of associations between cumulative exposure to HAV from the two occupational tools and Nerve Conduction Studies (NCS) parameters adjusted for age and BMI

NCS parameter	**Rock drill exposure 5.4m/s^2 (A8) right hand Unstandardized coefficient β[†] (95% CI)**	**Impact wrench exposure 1.2m/s^2 (A8) right hand Unstandardized coefficient β[†] (95% CI)**
Median nerve sensory CV (cZ-score) [‡]	-0.26 (-0.87, 0.35)	0.63 (0.04, 1.21)*
Median nerve distal motor latency (Z-score)	-0.26 (-0.85, 0.32)	0.53 (-0.32, 1.38)
Median nerve sensory amplitudes (cZ-score) [§]	-0.32 (-0.89, 0.25)	0.31 (-0.26, 0.90)
Ulnar nerve sensory amplitudes (cZ-score) [¶]	-0.25 (-0.80, 0.28)	0.21 (-0.43, 0.85)
Ulnar nerve motor CV across the elbow (Z-score)	0.65 (0.01, 1.29)*	0.33 (-1.23, 0.57)

*= Significant at 0.05 level. †= increase of NCS Z-score per log 10 unit of cumulative HAV exposure. ‡median nerve digital sensory CV cZ-score = combined Z-score of the median nerve sensory conduction velocity in the second, third and fourth fingers; § median nerve sensory amplitudes cZ-score = combined Z-score of the median nerve sensory amplitudes in the second, third and fourth fingers; ¶ ulnar nerve sensory amplitudes cZ-score = combined Z-score of the ulnar nerve sensory amplitudes in the fourth and fifth fingers.