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Occupational exposure to whole-body vibration and neck pain in the Swedish general population

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ABSTRACT

The primary aim of this study was to determine if occupational exposure to whole-body vibration (WBV) was associated with reporting neck pain. A cross-sectional study was conducted on a sample of the general population living in northern Sweden, aged 24–76 years. Data was retrieved through a digital survey that collected subjectively reported information on exposure to WBV and biomechanical exposures as well as neck pain. The study included 5,017 participants (response rate 44%). Neck pain was reported by 269 men (11.8%) and 536 women (20.2%). There was a statistically significant association between reporting occupational exposure to WBV half the time or more (adjusted OR 1.91; 95% CI 1.22–3.00) and reporting neck pain. In gender-stratified analyses, the same pattern was observed in men, while there were too few women to determine any association. We conclude that occupational exposure to whole-body vibration was associated with neck pain in men.

Practitioner summary: This cross-sectional, survey-based study investigated associations between self-reported occupational whole-body vibration and neck pain. It showed significant associations between frequent exposure to whole-body vibration and neck pain among men but not women. In occupational health care settings, whole-body vibration could be considered as a possible risk factor for neck pain.

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(MeSH): Neck pain; vibration; ergonomics; Sweden; occupational health

1. Introduction



1.1. Neck pain

Neck pain is one of the most common musculoskeletal disorders in the Western hemisphere, and it causes both suffering on an individual level as well as substantial societal costs due to sick leave as well as health care expenses (Shin et al. 2022). Statistics from the European Union report that musculoskeletal disorders in the neck, back and upper extremity are the most frequent causes of occupational disease and sick leave among workers in Europe (European Agency for Safety and Health at Work 2020). The point prevalence of neck pain in adult populations range from 6 to 22% and is generally higher among women than men, and higher in Scandinavian countries compared with other industrialised regions (Fejer, Kyvik, and Hartvigsen 2006). Several occupational biomechanical risk factors have been

determined, including prolonged work with flexed or extended neck, elevated arms, repetitive arm use, sitting, twisting or bending of the trunk, high quantitative demands, and effort-reward imbalance (Ariens et al. 2000; Swedish Agency for Health Technology Assessment and Assessment of Social Services 2022). Although there is ample clinical experience in the occupational health care setting that suggest adverse effects of whole-body vibration (WBV) in relation to neck pain, there is still scientific uncertainty regarding associations between the two.

1.2. Whole-body vibration (WBV)

WBV can be defined as more or less organised oscillatory motions of surfaces supporting the body (Griffin 2004), and can be transmitted from the seat, backrest or foot support of a vehicle (Rehn et al. 2002). In addition, operating vehicles can also include exposure to

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hand-arm vibration (HAV) through contact with the steering wheel or levers (Emkani et al. 2016). In the United States, it is estimated that more than four million workers are exposed daily to WBV, representing roughly 3% of the workforce (Johanning 2015). Of these, more than half a million operate heavy construction vehicles that generate a high exposure to WBV, such as bulldozers, graders, and backhoes (Johanning 2015). In Sweden, official statistics report that about 10% of men and 2% of women are occupationally exposed to WBV for at least one quarter of the time (Swedish Work Environment Authority 2020). The highest occurrence of exposure in Sweden is found among machine operators (where roughly 80% are exposed), followed by material management workers, forestry and farming professionals, and construction workers (Swedish Work Environment Authority 2020). WBV has been investigated in relation to a range of various adverse health effects, including but not restricted to musculoskeletal disorders, cardiovascular disease, neuropathies, prostate cancer, digestive problems, headaches, and dizziness (Krajnak 2018). In a previous systematic review of the evidence for adverse health effects from WBV, the authors concluded on a consistently increased risk for lumbar pain and sciatica (Burström, Nilsson, and Wahlström 2015). However, although an extension of the same anatomical structures, the literature regarding neck pain is scarcer, with substantial heterogeneity regarding methods for exposure and outcome assessment (Emkani et al. 2016; Bovenzi 2015; McBride et al. 2014; Mandal and Manwar 2017; Burström et al. 2017; Milosavljevic et al. 2012; Rehn et al. 2009; Hagberg et al. 2006; Palmer et al. 2001). Also, studies are often restricted to a specific line of work, and there has been few previous general population-based studies on the topic (Hagberg et al. 2006; Palmer et al. 2001). Since neck pain is a common complaint in the general population, more knowledge is needed regarding risk factors in this context, especially concerning potentially modifiable occupational factors. Such studies could also provide better basis for the assessment of workers' compensation claims.

1.3. Aim

The primary aim of this study was to determine if occupational exposure to whole-body vibration was associated with neck pain in the general population of northern Sweden. Secondary aims were to assess

gender differences and the presence of exposure-response patterns for occupational exposure to whole-body vibration in relation to neck pain.

2. Materials and methods

2.1. Study design and setting

This study was of cross-sectional design and based on a sample from the Swedish population register, including men and women between 24 and 76 years of age, living in one of the four northernmost counties in Sweden: Jämtland–Härjedalen, Västernorrland, Västerbotten, or Norrbotten. The study region was subdivided into 13 zones, and half of the sample was allocated in equally sized partitions to each zone, while the other half was proportionally distributed according to the population size in each zone. This approach was selected to ensure a sufficiently large sample from sparsely populated rural areas. The sampling and data collection have previously been described in detail (Stjernbrandt et al. 2022). The subjects were asked by regular mail to complete a digital survey during March and April of 2021, and one postal reminder was sent out after about one month. Those who were unable or reluctant to answer to the digital survey were offered a mail-in questionnaire upon request. The survey included questions on occupation, physical exposures during work, symptoms in different parts of the body, general health, and tobacco habits. The study protocol was approved by the Swedish Ethical Review Authority (DNR 2020-06707). Informed consent was obtained from all participants included in the study when starting the digital survey.

2.2. Description of materials

Numerical data were described as mean values with standard deviation (SD), while categorical variables were presented as numbers and valid row percentages, unless otherwise specified. Cases with neck pain were defined using the following questionnaire item: *having ache/pain in the neck/shoulder*, where answers were given on a four-graded scale including the options *none; insignificant; slightly; or a lot*. Answering *a lot* was considered a positive response while subjects with other responses were considered to be healthy references. For WBV exposure, one item was used: *being exposed to vibration that makes the whole body shake or vibrate (e.g. in a tractor)*. The answer was given on a six-graded time scale describing the proportion of the working time exposed to WBV: *never; one tenth; one quarter, half, three quarters; or almost always*. In addition, several questionnaire items

were used to assess biomechanical exposures, asking about the frequency of heavy lifting (*lifting at least 15 kilograms per unit multiple times per day*); forward-bent postures (*work bent forward, without support from hands or arms*); twisted postures (*work in a twisted position, e.g. with a rotated back*); and sitting (*work in a seated position*). The answers on these items were reported on five-graded time scales, including *never*; *a couple of days per month*; *one day per week*; *a couple of days per week*; and *every day*. Having *experience of mental stress during the last month* was asked about with the following response alternatives: *none*; *very little*; *some*; *quite a lot*; or *very much*. Additional independent variables used for adjusting were: *age (years)*; *gender (male/female)*; *body mass index (BMI; kg/m²)*; and *current daily smoking (yes/no)*. These variables were selected for adjusting the models based on the authors' preunderstanding of potential confounding. Occupation was reported in free-form text, and manually coded in accordance with the International Standard Classification of Occupations (ISCO) (International Labour Organization 2012).

2.3. Statistical analysis

WBV exposure was grouped into three larger categories: *never*; *one tenth to one quarter of the time*; and *half the time or more*. However, all six original categories were used for exposure-response analyses. BMI was categorised based on clinically used thresholds for under- and overweight (World Health Organization 1995). Statistically significant differences in frequencies between categories were determined using Pearson's chi-squared test. Monotonic correlation between scales was investigated using Spearman's rank correlation coefficient, where a value below -0.3 or above 0.3 was considered relevant. Binary logistic regression was used for simple and multiple analyses, and results presented as odds ratios (OR) with 95% confidence intervals (95% CI). No correction for multiple testing was performed. A p value <0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics for Windows (Version 28, IBM Corporation, Armonk, NY, USA).

3. Results

3.1. Participants and descriptive data

In total, there were 5,208 responses to the survey, yielding a response rate of 44.4%. Due to multiple or erroneous data entries, 191 survey responses could not be used, which left 5,017 subjects available for

analysis. The mean (SD) age was 57.8 (13.0) years, mean (SD) BMI 26.4 (4.5) kg/m², and 2,703 (53.9%) subjects were female. Neck pain was reported by 269 men (11.8%) and 536 women (20.2%).

3.2. Exposure to whole-body vibration and biomechanical factors

Any occupational exposure to WBV was reported by 440 men (21.2%) and 61 women (2.8%), and exposure for at least one quarter of the time by 200 (9.6%) and 30 (1.4%), respectively. Among those who were exposed to WBV half the time or more, the most common occupations among men were drivers and mobile plant operators (31.4%), stationary plant and machine operators (7.4%), metal, machinery, and related trades workers (5.8%), building and related trades workers (5.0%) and skilled forestry, fishery, and hunting workers (5.0%). For women, the most common occupational group was also drivers and mobile plant operators (13.6%). Further descriptive data are presented in Table 1. The correlation coefficients between WBV and biomechanical exposure variables ranged from 0.31 to 0.78 for all variables except for sitting, which showed inverse relations, ranging from -0.04 to -0.09 (Table 2).

3.3. Associations between whole-body vibration and neck pain

For all subjects, there was a statistically significant association between occupational exposure to WBV one tenth to one quarter of the time (OR 1.57; 95% CI 1.12–2.21) as well as half the time or more (OR 1.91; 95% CI 1.22–3.00) and reporting neck pain, after adjusting for age, gender, BMI, smoking, heavy lifting, forward-bent postures, twisted postures, sitting, and mental stress. In gender-stratified adjusted analyses, the same pattern was seen in men (OR 1.80; 95% CI 1.21–2.68 and OR 1.98; 95% CI 1.18–3.35, respectively) but not in women (OR 0.73; 95% CI 0.30–1.75 and OR 1.99; 95% CI 0.69–5.76, respectively) after adjusting for the same covariates except gender (Table 3). Analyses of crude and adjusted exposure-response functions are presented in Figure 1.

3.4. Sensitivity analyses

To combat the potential issues of non-workers in the cohort, we performed sensitivity analyses that restricted inclusion to only those who worked according to occupational title ($N = 3,843$), as well as a

Table 1. Descriptive characteristics of the study participants.

Variable	Categories	Men				Women			
		Neck pain		References		Neck pain		References	
		N	%	N	%	N	%	N	%
Participants	–	269	11.8	2,003	88.2	536	20.2	2,122	79.8
Body mass index (kg/m ²)	BMI <18.5	0	0.0	10	0.5	11	2.1	22	1.1
	18.5 ≤ BMI <25	82	31.1	721	36.6	215	41.5	985	48.0
	25 ≤ BMI ≤30	127	48.1	906	45.9	168	32.4	703	34.3
	BMI >30	55	20.8	335	17.0	124	23.9	340	16.6
Smoking	Yes	10	3.7	57	2.9	33	6.3	84	4.0
	No	258	96.3	1,934	97.1	495	93.8	2,025	96.0
Mental stress	Quite a lot/very much	66	25.5	231	11.9	195	38.2	352	17.6
	None/very little/some	193	74.5	1,718	88.1	315	61.8	1,644	82.4
Whole-body vibration exposure	None	149	63.4	1,467	80.8	446	96.3	1,739	97.6
	One tenth of the time	43	18.3	193	10.6	7	1.5	24	1.3
	One quarter of the time	16	6.8	56	3.1	1	0.2	7	0.4
	Half the time	6	2.6	40	2.2	3	0.6	4	0.2
	Three quarters of the time	11	4.7	26	1.4	4	0.9	2	0.1
	Almost always	10	4.3	33	1.8	2	0.4	6	0.3
Biomechanical exposures (one day per week or more)	Heavy lifting	90	38.7	462	25.4	94	20.6	187	10.5
	Forward-bent postures	87	37.6	420	23.2	149	32.6	355	20.1
	Twisted postures	86	37.3	385	21.2	135	29.8	319	18.0
	Sitting	153	66.6	1,183	65.6	336	73.5	1,217	69.1

The numerical sum of each variable is affected by missing data and valid column percentage are presented.

Table 2. Spearman's rank correlation coefficients between biomechanical exposure variables.

	Whole-body vibration			
Heavy lifting	0.42 (0.39–0.44)	Heavy lifting		
Forward-bent postures	0.31 (0.28–0.34)	0.66 (0.64–0.69)	Forward-bent postures	
Twisted postures	0.34 (0.31–0.37)	0.63 (0.61–0.66)	0.78 (0.76–0.80)	Twisted postures
Sitting	–0.06 (–0.09––0.03)	–0.09 (–0.12––0.06)	–0.05 (–0.08––0.02)	–0.04 (–0.01––0.07)

All correlations were statistically significant at the 0.05 level and ninety-five percent confidence intervals are presented in parentheses.

separate restriction on age (24–65 years; $N = 3,301$). These procedures had very little impact on the statistical associations between WBV and neck pain (Table 4).

4. Discussion

4.1. Main findings and interpretation

There was a statistically significant association between occupational exposure to whole-body vibration and neck pain among men, but not women. There were however very few exposed female subjects. There was not a convincing exposure-response relation for the time-graded exposure categories, regardless of gender. Finally, there were statistically significant correlations between whole-body vibration and biomechanical exposures, such as heavy lifting and forward-bent postures.

As one of few general population-based studies, our study showed a significant association between occupational WBV and neck pain, which is consistent with previous studies with various sample sizes and in different occupational settings. One previous study was based on pooled data from Swedish national statistics (The Work Environment Surveys performed by the Swedish Work Environment Authority) and

included a sample of 9,798 subjects (Hagberg et al. 2006). In cross-sectional analyses, the authors reported a prevalence ratio (PR) of neck pain of 1.4 (95% CI 1.2–1.7) among those occupationally exposed to WBV half the time or more, after adjusting for age, gender, lifting and frequent bending (Hagberg et al. 2006). In contrast, a British cross-sectional population-based study ($N = 12,907$) reported no consistent association between WBV and neck pain, other than for a subset of employed male subjects exposed to WBV during the last week with neck pain reported during the last year (PR 1.1; 95% CI 1.0–1.2), after adjusting for age, smoking, lifting weights, work with elevated arms, keyboard use, HAV exposure, frequent headaches, and tiredness or stress (Palmer et al. 2001). Most other previous studies have focussed on highly exposed occupational groups in a single context, such as transportation or mining. In a Swedish study on male professional offroad vehicle drivers ($N = 431$), there were statistical associations between driving forest machines, snowmobiles, and snow groomers in relation to reporting neck pain (prevalence rate ratio 1.9; 95% CI 1.4–2.5, 1.9; 95% CI 1.4–2.5, and 2.2; 95% CI 1.6–2.0, respectively) after adjusting for age, smoking, and job strain (Rehn et al. 2002). In another Swedish cross-sectional study on male forest machine

Table 3. Logistic regression for occupational exposure to whole body vibration in relation to reporting neck pain.

	Men				Women			
	Cases N (%)	References N (%)	Crude OR (95% CI) Reference	Adjusted OR (95% CI) Reference	Cases N (%)	References N (%)	Crude OR (95% CI) Reference	Adjusted OR (95% CI) Reference
Whole-body vibration	595 (85.2)	3,206 (89.1)	1.29 (0.97–1.71)	1.57 (1.12–2.21)^a	149 (63.4)	1,467 (80.8)	2.33 (1.68–3.25)	1.80 (1.21–2.68)^b
Never	67 (9.6)	280 (7.8)			59 (25.1)	249 (13.7)		
One tenth to one quarter of the time								
Half the time or more	36 (5.2)	111 (3.1)	1.75 (1.19–2.57)	1.91 (1.22–3.00)^a	27 (11.5)	99 (5.5)	2.69 (1.70–4.24)	1.98 (1.18–3.35)^b

OR: odds ratio; 95% CI: ninety-five percent confidence interval.

Bold values were statistically significant at the 0.05 level.

^aAdjusted for age, gender, body mass index, smoking, heavy lifting, forward-bent postures, twisted postures, sitting, and mental stress.

^bAdjusted for age, body mass index, smoking, heavy lifting, forward-bent postures, twisted postures, sitting, and mental stress.

operators ($N=333$), 14 different measures of WBV exposure were utilised but none showed significant associations to the reporting of neck pain (Rehn et al. 2009). For instance, the OR for total number of years of WBV exposure in relation to neck pain was 0.9 (95% CI 0.5–1.8) after adjusting for working positions involving bending or twisting of the spine. In a cross-sectional study on male and female mine workers in the Barents region, vehicle operators ($N=757$) had a significantly higher occurrence of neck pain than non-operators (OR 1.41; 95% CI 1.10–1.80) after adjusting for age, gender, smoking, height, weight, and perceived stress (Burström et al. 2017). There is also a number of previous studies performed outside of Scandinavia. In an Italian prospective study on male professional drivers ($N=537$), cumulative WBV dose was significantly associated with reporting episodes of neck pain (OR 1.26; 95% CI 1.02–1.56), after adjusting for smoking, BMI, alcohol use, educational level, physical activity level, previous exposures to WBV and heavy workload, and survey time (Bovenzi 2015). In a cross-sectional Iranian study on male drivers of heavy mining vehicles ($N=288$), there was an association between WBV and neck pain in crude analyses (OR 1.6; 95% CI 1.1–2.4) but not after adjusting for age, BMI, smoking, work experience, and exercise habits (OR 1.4; 95% CI 0.9–2.2) (Emkani et al. 2016). In a cross-sectional Indian study on operators on heavy mining equipment where gender was not reported ($N=46$), WBV exposure was associated with neck pain (OR 12.1; 95% CI 1.7–89.4) after adjusting for age, BMI, smoking, alcohol use and exercise habits (Mandal and Manwar 2017). In a cross-sectional New Zealand study on mainly male locomotive engineers ($N=340$), being subjected to high cumulative WBV exposure was associated with prolonged neck pain (OR 2.4; 95% CI 1.5–4.0) after adjusting for physical and mental strain (McBride et al. 2014). In another New Zealand study that focussed on mainly male farmers and rural workers driving all-terrain vehicles ($N=130$), the daily WBV dose was associated with neck pain during the last year (OR 1.10; 95% CI 1.0–1.2) in univariate analysis, while no multiple regression model was presented (Milosavljevic et al. 2012). Finally, an Australian study on male farmers driving tractors ($N=179$) reported a high prevalence of neck pain and a subjectively perceived relation to WBV exposure (Scutter, Türker, and Hall 1997). To conclude, most previous studies are of cross-sectional design, have focussed on specific occupational groups, and concluded on significant association between WBV and neck pain, with effect sizes that were roughly comparable with the results of our

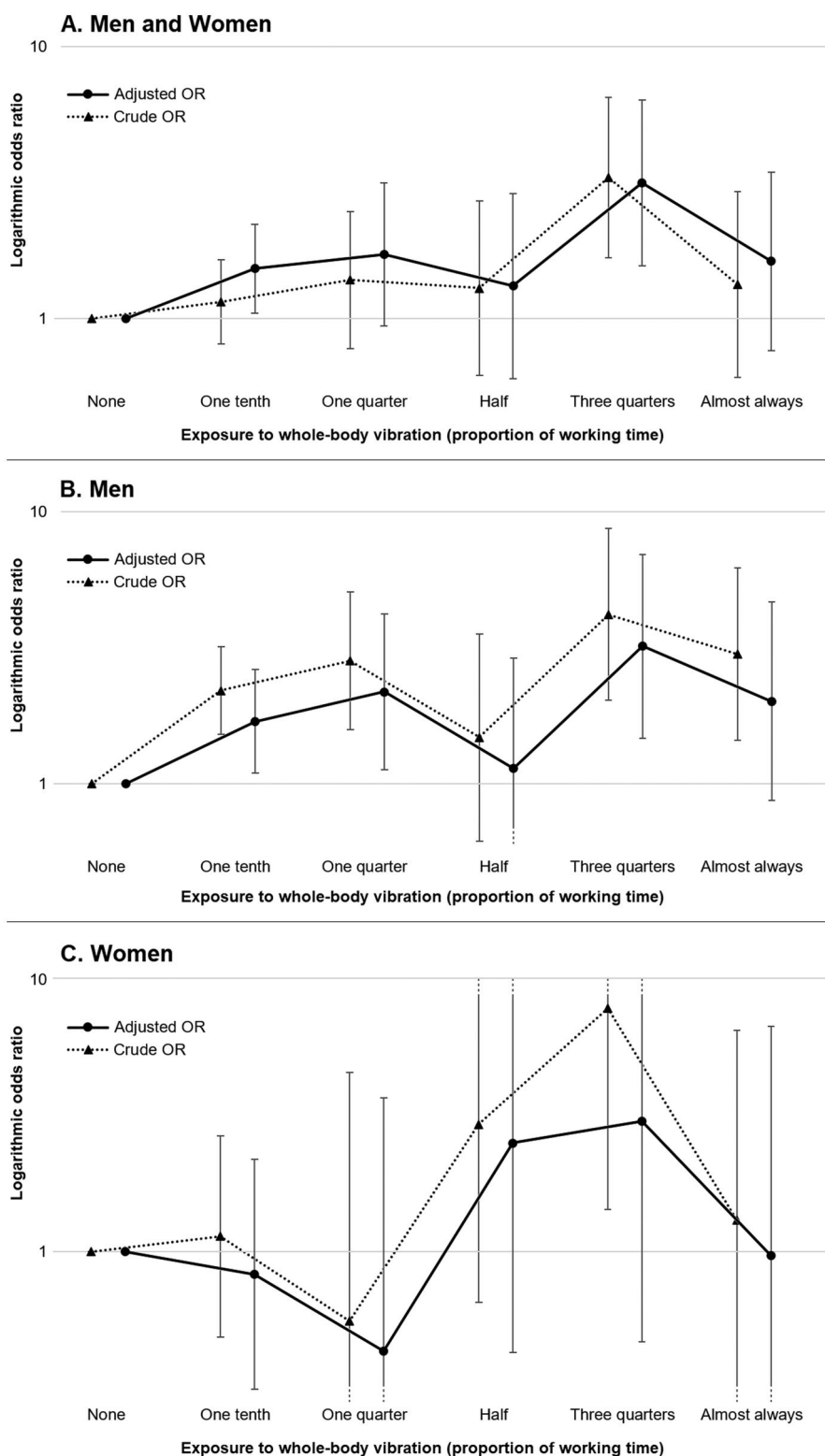


Figure 1. Exposure-response graphs for the association between occupational exposure to whole-body vibration and neck pain, for men and women together (A), as well as men (B) and women (C) separately.

study. In contrast, the study on Indian miners reported a much larger effect size, which might be explained by a high exposure to both WBV and awkward postures (Mandal and Manwar 2017). However, these

results should be interpreted cautiously, since this study lacked in statistical power which resulted in large confidence intervals. Finally, a consequent exposure-response relation has not been demonstrated for

Table 4. Sensitivity analyses on logistic regression for occupational exposure to whole body vibration in relation to reporting neck pain (men and women).

	I. Original analyses (<i>N</i> = 5,017) ^a OR (95% CI)	II. Subjects working according to occupational title (<i>N</i> = 3,843) ^a OR (95% CI)	III. Subjects of working age (24–65 years) (<i>N</i> = 3,301) ^a OR (95% CI)
Whole-body vibration			
Never	Reference	Reference	Reference
One tenth to one quarter of the time	1.57 (1.12–2.21)	1.50 (1.03–2.17)	1.71 (1.16–2.52)
Half the time or more	1.91 (1.22–3.00)	1.95 (1.20–3.18)	1.97 (1.19–3.26)

OR: odds ratio; 95% CI: ninety-five percent confidence interval.

Bold values were statistically significant at the 0.05 level.

^aAdjusted for age, gender, body mass index, smoking, heavy lifting, forward-bent postures, twisted postures, sitting, and mental stress.

WBV in relation to neck pain (Rehn et al. 2002; Burström et al. 2017).

4.2. Exposure assessment

In our study, occupational exposure to WBV for at least one quarter of the time was reported by roughly 10% of men and 1% of women. This can be compared to official Swedish statistics reporting exposure on a similar questionnaire item for about 10% of men and 2% of women (Swedish Work Environment Authority 2020), as well as a previous Swedish study reporting exposure in about 12% of men and 1% of women (Hagberg et al. 2006), thus all being very similar. The occupations that entailed frequent exposure to WBV in our study were also well in line with what has previously been reported in a Swedish setting, where skilled agricultural, forestry and fishery workers, plant and machine operators, and craft and related trade workers were among the most highly exposed (Hagberg et al. 2006).

Importantly, the methods for assessing WBV exposure varied in the previously cited studies, from dichotomous categorisation based on occupation (e.g. driver/non-driver) (Mandal and Manwar 2017; Burström et al. 2017) to detailed standardised vibration measurements on representative samples or the whole study population (Emkani et al. 2016; Bovenzi 2015; McBride et al. 2014; Milosavljevic et al. 2012; Rehn et al. 2009). The exposure was also categorised in different manners in previous studies, where some authors considered cumulative WBV exposure while others focussed on maximum intensity of exposure regardless of duration. Importantly, several previous studies have shown that machine operators are commonly exposed above the action value of 0.5 m/s² for WBV (European Council 2002), for instance in heavy mining vehicles, agricultural equipment, and forest machines (Emkani et al. 2016; Rehn et al. 2009; Rehn et al. 2005; Zeng et al. 2017; Fethke et al. 2018). In a Swedish database with exposure measurements from a wide variety of vehicles, exposure levels range from about 0.4–0.8 m/s² in vehicles typically used in the

construction industry, 0.7 m/s² for tractors in agriculture and 0.5 m/s² for mining haul trucks (The Vibration Database 2023). In our study, WBV exposure was categorised in proportion of the working time, but we did not ask about the duration or magnitude of exposure, although both these dimensions have been suggested to be relevant for musculoskeletal outcomes (Rehn et al. 2009). Finally, it should be stated that when WBV includes transient mechanical shocks (e.g. unloading cargo or driving over bumps), the current standard (ISO 2631–1) may underestimate the associated risks (Johanning 2015). For operators of some types of vehicles, transient mechanical shocks may actually constitute a larger health risk than continuous low-intensity WBV exposure (Milosavljevic et al. 2012; Mayton et al. 2008). One interesting example that underlines this notion is a cluster investigation of cervical herniated discs among dump truck drivers that were exposed to impact shocks during loading of the trucks (Lan et al. 2016).

4.3. Outcome assessment

In contrast to the exposure assessments, all outcome assessment in the studies cited above were rather crude and based on questionnaire items with different time scales. One commonly used tool in several of the previous studies has been the Nordic Questionnaire on Musculoskeletal Symptoms (Kuorinka et al. 1987) that has been shown to have good validity and reliability but lacks in specificity (Kuorinka et al. 1987; Franzblau et al. 1997). It contains questions about musculoskeletal symptoms during the last seven days as well as the last twelve months, offering some time perspective. In our study, we did not specify the time-frame for reporting neck pain, and this meant that we could not conclude on the duration of symptoms. Previous studies have concluded that musculoskeletal disorders in occupational settings are of multifactorial origin, where combined exposures to WBV, physical overload, and poor psychosocial work environment are likely contributors to the development of neck pain (Bovenzi 2015). In addition, environmental factors

(e.g. ambient cold and draft) may also play a role (Emkani et al. 2016; Burström et al. 2017; Stjernbrandt and Hoftun Farbu 2022). In epidemiological studies on WBV, there is obvious risk for confounding due to ergonomic factors, such as awkward neck posture and prolonged sitting, since many of those exposed to WBV are operators of vehicles where those factors are commonly occurring (Johanning 2015; Hagberg et al. 2006). Previous studies have underlined the importance of considering ergonomic confounders when evaluating WBV in relation to neck pain (Hagberg et al. 2006), and some authors have even concluded that such biomechanical exposures might indeed play a larger role in the development of neck pain than WBV in itself (Rehn et al. 2009). To complicate matters further, there is a large covariance between WBV and different biomechanical exposures as demonstrated in Table 2, which makes it hard to adjust a regression model to isolate the effects of WBV. In one of the previous Swedish studies of similar design to ours, heavy lifting and twisted postures had to be omitted from multiple regression modelling because of an agreement with WBV exceeding 80% (Hagberg et al. 2006). However, in our study, WBV exposure appeared to be an independent associated factor for neck pain even after adjustment for other biomechanical exposures.

Regarding pathophysiological mechanisms, biodynamic studies have shown that WBV can be transmitted from the seat to the cervical spine and shoulders (Griffin 1996). The transmissibility has been reported to be dependent upon age, gender, anthropometry, and posture (Paddan and Griffin 1988). The complex interplay of different mechanisms causing damage to spinal structures as a result of WBV exposure have previously been described in detail (Bongers and Boshuizen 1992). In brief, dynamic loading of the spine has been suggested to reduce nutritional delivery to the intervertebral discs with subsequent degeneration, as well as to promote development of spondylosis and deterioration of subchondral bone structure (Scutter, Türker, and Hall 1997). Apart from direct mechanical detrimental effect on cervical discs and joints, WBV has also been demonstrated to increase cervical paravertebral muscular activity (Cursiter and Harding 1974). To conclude, experimental physiological studies support the findings of epidemiological studies, and suggest that WBV can adversely affect the structural integrity of the cervical spine as well as induce a compensatory muscular response, which both can evoke neck pain (Bovenzi 2015). Importantly, some subjects that are exposed to WBV when driving vehicles are also exposed to HAV

through contact with the steering wheel or levers (Emkani et al. 2016), and it is possible that this also affects the occurrence of neck and shoulder pain by transmission through the upper extremity (Ariens et al. 2000).

4.4. Gender aspects

There were several important aspects in our study to highlight with regards to gender, in this context referring to biological differences. Firstly, there were very few women that reported occupational exposure to WBV in our study, a general pattern that has previously been described for Swedish workers (Hagberg et al. 2006). As an exemption, there has been a reported steady increase of female drivers of mining vehicles (i.e. haul trucks) during the last decades in Scandinavian countries (Burström et al. 2017), and this might lead to an increase in exposed female workers in the future. Other situations where female drivers have been reported to be highly exposed in Sweden are when driving trucks and forklifts (Skröder et al. 2020). Secondly, neck pain was much more common among women than men in our study. This has been shown in other Swedish studies, and it has been concluded that female gender can be considered both a risk factor for neck pain as well as a negative prognostic factor for recovery (Skillgate et al. 2012). However, in our study, there were no statistically significant associations between WBV and neck pain among women in adjusted regression analyses. We believe that our study was not sufficiently statistically powered to determine any potential effect of WBV on neck pain among women, and we encourage further studies on the topic. Previous authors have reported that women are consistently more likely to report musculoskeletal symptoms (Fillingim et al. 2009) and this has also been shown among WBV-exposed female drivers (Hooftman et al. 2009). One explanation could be that the driver compartments in vehicles are generally designed to accommodate a typical male physical frame, which could cause ergonomic disadvantages for women of different stature (Burström et al. 2017). However, whether there is a biologically based gender difference in susceptibility to WBV has not yet been determined (Hooftman et al. 2009).

4.5. Limitations and strengths

One important limitation in our study was the rather low response rate (44%) that could have introduced a sampling bias and reduced the generalisability of the

results. Although the aim of our study was not explained to the study participants, there is a possibility that symptomatic subjects could have responded preferentially, or better recalled WBV or biomechanical exposures, leading to a systematic bias in exposure assessments. However, it has previously been reported that subjects with musculoskeletal pain do not necessarily overestimate their previous physical workload (Hollmann et al. 1999). The questions used for exposure assessment have also been investigated by Statistics Sweden and found to have a good validity (Hagberg et al. 2006). Moreover, the cross-sectional nature of data meant that time-relations could not be concluded on. Subjects with neck pain could have left certain occupations or avoided strenuous exposures, and that could have introduced a healthy worker effect. The outcome parameter in our study was rather unspecific and included both neck and shoulder pain. Previous authors have suggested that these anatomically adjacent regions are not always separated by study participants, and that causal factors for pain complaints likely share common biomechanical grounds (Palmer et al. 2001). It has also been suggested that the neck and shoulder could be considered one functional entity due to the close anatomical proximity and often overlapping symptom distribution (Rehn et al. 2002). In support of this view, it has been reported that roughly half of drivers with neck pain also have radiating pain in the shoulders (Rehn et al. 2009). Some important psychosocial risk factors for neck pain, such as high quantitative demands and effort-reward imbalance, were not considered in our study. Moreover, information about previous injuries, physical activity, and alcohol habits was not available. Neither was socio-economic status considered, although previous authors have reported that it has relevant repercussions on the prevalence of neck pain (Hogg-Johnson et al. 2008). Our study was designed to include subjects of working age, but the age composition of our sample included a substantial proportion of participants above the current Swedish retirement age of 65 years. However, when restricting the sample in our sensitivity analyses (Table 4), the results were virtually unchanged. Also, all models were adjusted for age (as a continuous parameter). Age would also be expected to be strongly correlated to cumulative WBV exposure. Taken together, we do not believe that the effect of age confounded the statistical associations in any major way. Smoking has been associated with a general increase in musculoskeletal pain (Coggon et al. 2013), and some authors have also suggested that drivers who smoke while driving can

adopt an unsuitable posture that could increase the risk of neck pain specifically (Emkani et al. 2016). However, the prevalence of current daily smoking in our study sample was low and adjusting for tobacco habits had little influence on the results. To conclude, the results of our study should be considered as hypothesis-generating, and we encourage future confirmative studies of prospective design. However, when comparing our results to the previous literature, we believe that our results are well in line with what has been found by most other authors. Also, to our knowledge, this is one of the largest studies on WBV and neck pain to date, and it broadens the perspective from specific occupational groups to the general population. Also, we collected ample background data on study participants and their biomechanical exposures to enable thorough adjustment of regression analyses, which we believe increase the robustness of the conclusions in this study.

4.6. Implications

There are several potential implications of our study. When planning health surveillance and clinical assessment of WBV-exposed workers, one might consider a broader focus than only the lumbar spine and include symptoms and signs in the neck and shoulders. Since neck pain is very common in the general population, a preventive effort in the occupational setting may have a relevant impact even if the attributable fraction to WBV was found to be low. The European directive on WBV is focussed on low back outcomes (European Council 2002), and might need to be revised as more studies on other important musculoskeletal disorders emerge.

4.7. Conclusions

We conclude that occupational exposure to whole-body vibration was associated with neck pain in men.

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Author contributions

AS researched the literature, conceived the study, and formulated the aims. AS, JW, and CL developed the protocol and collected the data. AS and JW applied for ethical

approval. HP aided in database construction. AS performed data analyses and wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The dataset used during the current study can be made available upon reasonable request to the corresponding author.

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