Available online at www.sciencedirect.com
ScienceDirect
Journal of Sound and Vibration 298 (2006) 492–498
JOURNAL OF SOUND AND VIBRATION
www.elsevier.com/locate/jsvi

The association between whole body vibration exposure and musculoskeletal disorders in the Swedish work force is confounded by lifting and posture

Mats Hagberg[a,*], Lage Burström[b], Anna Ekman[a], Rebecka Vilhelmsson[a]

[a]*Occupational and Environmental Medicine, Sahlgrenska Academy and University Hospital, UGOT, Göteborg, Sweden*
[b]*National Institute for Working Life—North, Umeå, Sweden*

Received 7 May 2006; received in revised form 13 May 2006; accepted 8 June 2006
Available online 1 August 2006

Abstract

This was a cross-sectional study based on material representing the Swedish work-force from a survey conducted in 1999, 2001 and 2003 by Statistics Sweden. Exposure to whole body vibration (WBV) was prevalent among agricultural, forestry, fishery workers and among plant and machinery operators based on a sample of 40,000 employed persons. Approximately 70% responders, that are 9798 persons answered both the interview and the questionnaire for the analysis of exposure–response. Exposure to WBV at least half the working time was associated with prevalence ratios above two for musculoskeletal symptoms in the low back, neck, shoulder/arm and hand among workers. When the exposure factors lifting and frequent bending were added to a multivariate analysis, surprisingly the magnitude of association was low between low back symptoms and WBV exposure. Interestingly, the relation between WBV exposure and symptoms in the neck, shoulder/arm and hand had the same or higher magnitude of association even when the possible confounders were in the model. For the neck, low back and shoulder/arm there was a visible increase in prevalence ratio (as high as 5 times) when combined exposures of WBV, lifting, frequent bending, twisted posture and noise were included in the analysis.

1. Introduction

Whole body vibration (WBV) is mechanical energy oscillations which are transferred to the human body as a whole. This occurs usually through a supporting system such as a seat or platform. In a postal questionnaire to a random community sample Palmer and co-workers found that the most common sources of occupational exposure to WBV in the United Kingdom were cars, vans, forklift trucks, lorries, tractors, buses, and loaders [1]. In the European directive WBV means "the mechanical vibration that, when transmitted to the whole body, enters risks to the health and safety of workers, in particular lower back, morbidity and trauma of the spine" [2]. In a review by NIOSH 1997 the conclusion was that there was strong evidence for a positive association between exposure to WBV and back disorders [3]. A majority of studies reviewed in the NIOSH document demonstrated a dose–response relationship between exposure to WBV and low back disorders [3].

*Corresponding author. Tel.: +46 31 77 36 305; fax: +46 31 40 97 28.
E-mail address: mats.hagberg@amm.gu.se (M. Hagberg).

0022-460X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsv.2006.06.024

In a review of studies published 1986–1997 Bovenzi and Hulshof concluded that occupational exposure to WBV was associated with an increased risk for low back pain (LBP), sciatic pain, and degenerative changes in the spinal system [4]. However, in the Lings and Leboeuf-Yde review they concluded a probable association between WBV and LBP but it was not possible, on the basis of existing literature, to decide whether WBV-exposure per se is capable of causing LBP, or if WBV constitutes a risk only in combination with other factors, such as prolonged sitting and certain work postures [5].

Workers exposed to WBVs are often simultaneously exposed to other ergonomic stressors such as awkward postures and manual material handling (lifting) [6]. In a questionnaire study Palmer and co workers concluded that the burden of LBP in Britain among men and women of working age from occupational exposure to WBV was smaller than that attributable to lifting at work [6]. Musculoskeletal symptoms from other regions than the low back have not been addressed by many researchers or the EU directive. Among all-terrain vehicle drivers, significantly increased prevalence ratios within the range of 1.5–2.9 were revealed for symptoms from the neck, shoulder and thoracic regions during the previous year [7]. This indicated that WBV might cause health effect in other body regions besides the low back.

2. Aim

To study the occurrence of exposure to WBV in the Swedish work force. Furthermore the aim was to study the relation between musculoskeletal symptoms and exposure to WBV and whether exposure to other ergonomic factors confounded this relationship.

3. Methods

3.1. Study base

This was a cross-sectional study based on material from a survey conducted in 1999–2003 by Statistics Sweden (SCB), by order of the National Board of Occupational Safety and Health. The Work-environmental survey conducted by SCB Sweden consists of both a phone interview and a questionnaire sent by mail.

3.1.1. Occurrence of WBV in different occupations

For a description of occurrence of whole-body vibration in different occupations three surveys 1999, 2001 and 2003 were added together by Statistics Sweden giving a sample of over 40,000 employed persons aged 16–65 years. The definition by Statistics Sweden of exposed was that they during at least one fourth of their working time were exposed to ''vibrations that make your whole body vibrate'' [8].

3.1.2. Musculoskeletal disorders, WBV and other risk factors

This was a cross-sectional study based on material from a survey conducted in 1999 by SCB, by order of the National Board of Occupational Safety and Health. In 1999, 12,546 employed persons were interviewed by through phone calls (88% responders). Approximately 70% responders, that is 9798 persons answered both the interview and the questionnaire. These responders were the study group in the analytical study of risk factors for musculoskeletal disorders. For individual questions the level of non-response was between 1% and 3%. There were different categories of duration of exposure. We chose the definition that individuals characterized as exposed to *WBV* had answered that they during *half their working* time were exposed to ''vibrations that make your whole body vibrate''. There were different categories of duration of symptoms. We chose the definition that musculoskeletal symptom was defined of the individual as having pain in the specific region ''*at least 1 day per week*''. The regions that were considered were the low back, upper back, neck, shoulder and hand. Manual material handling was addressed by two questions ''Do you have to lift loads heavier than 25 kg multiple times per day, more than 1 day per week?'' and ''Do you have to lift loads between 15 and 25 kg multiple times per day, more than one day per week?'' Awkward postures were defined as frequent bending and rotation of the trunk and working with the trunk in a rotated position. *Frequent bending* was defined by the question ''Does it occur in your work that you bend or twist your body in the same way many times per hour during several hours the same day at least 1 day per week?'' *Twisted posture* was defined

as ''Do you sometimes work with your body in a twisted posture, at least half your working time?'' The exposure level was set to ''occurrence at least half the working time''. Exposure to the factor noise was defined as ''Are you exposed to noise in your work that is so high that you cannot talk in a normal tone at least half the working time?''

3.2. Statistics

This was a cross-sectional study. Analysis was made using SAS version 8 [9]. The prevalence was for some factors high and thus associations were consistently computed as prevalence ratios rather than odds ratios to simplify interpretation [10]. A prevalence ratio with a 95% confidence interval not including one was considered statistically significant. The relation between musculoskeletal symptoms and different exposures controlled for gender and age was computed using the proportional hazard procedure ''proc phreg'' in the SAS program. Thus, multivariate analysis allowed for controlling for possible ergonomic exposures that may confound the relation between health outcome and WBV. The interrelationship (multicollinearity) between exposure variables was examined and those variables that had 80% or more agreement were not included in the model. To obtain the prevalence ratios in the multivariate analysis ''proc phreg'' in SAS was used with the time set to 1. We also examined the combination of exposure and effect on prevalence ratio. Although multiple comparisons were made we did not adjust for this through Bonferoni or any other transformation. Our rationale was that the determinants of the work system examined for an association with musculoskeletal symptoms were not chosen at random but each with a clear hypothesis. Furthermore some authors point out that adjusting statistical significance for the number of tests may create more problems than it solves [11].

4. Results

Exposure to WBV was prevalent among agricultural, forestry, fishery workers and among plant and machinery operators (Table 1). The prevalence to WBVs ''vibrations that make your whole body vibrate'' at least one-fourth of the working time in the Swedish work force (16–64 years) was 11.8% for males and 1.4% for females. The prevalence ratios were above two for musculoskeletal symptoms in the low back, neck, shoulder/arm and hand among workers exposed to WBV at least half the working time (Table 2). The prevalence of WBVs at least half the working time was 3%. The prevalence of lifting (15–25 kg) was 24%, lifting (>25 kg) was 14%, frequent bending was 37%, twisted posture was 15% and noise was 14% in the Swedish work force. WBV and lifting (>25 kg), WBV and twisted posture, WBV and noise had 80% or more agreement and were not included in the multivariate model. In the multivariate analysis where possible confounders (that had less than 80% agreement with WBV exposure) to the relation between musculoskeletal symptoms and WBV were taken into consideration surprisingly the magnitude of association was low between low back symptoms and WBV exposure (Table 3). Interestingly the relation between WBV exposure and

Table 1
Proportion employed (percent) exposed to whole body vibrations ''vibrations that makes your whole body vibrate'' at least one-fourth of the working time in the Swedish work force (16–64 years)

Occupation	Men (%)	Women (%)	Total (%)
Skilled agricultural, forestry and fishery workers	53.5	14.2	44.0
Plant and machine operators	26.9	10.8	24.1
Craft, trade workers, miners, construction workers	16.1	6.6	15.5
Elementary occupations cleaners janitors etc	15.9	3.5	7.7
Clerks, warehouse workers	16.5	1.1	5.4
Managers, legislators, senior officials	2.1	0.1	1.5
Service and shop sales workers	3.7	0.8	1.5
Technicians and associated professionals	2.3	0.4	1.4
Professionals e.g. teachers computer technicians	0.5	0.2	0.3

The prevalence for employed males was 11.8% and for females 1.4%. The prevalence is based on three samples 2001, 2003 over 40,000 employed persons representing the Swedish work force [8].

Table 2
The relation between musculoskeletal symptoms (at least 1 day per week) and exposure to whole body vibration at least half of the working time

	Exposed		Not exposed	Total	PR	95% CI	
	Cases	Non-cases	Cases				
Low back	77	206	1319	8801	2.18	1.72	2.76
Neck	101	191	1936	8892	2.23	1.81	2.74
Shoulder/arm	106	173	1774	8810	2.57	2.10	3.14
Hand	63	215	858	8677	3.27	2.51	4.26

Prevalence ratios adjusted for gender and age (proportional hazard model).

Table 3
Multivariate analysis of musculoskeletal symptoms in relation to ergonomic stressors and individual factors

Determinant	Low back			Neck			Shoulder/arm			Hand		
	PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
Gender (male=1, female=2)	1.4	1.30	1.56	1.8	1.66	1.94	1.6	1.51	1.78	1.7	1.48	1.86
Age (continuous)	1.01	1.005	1.013	1.01	1.005	1.012	1.02	1.019	1.026	1.02	1.018	1.027
Whole body vibration (at least half of the working time)	1.4	1.16	1.71	1.4	1.16	1.67	1.6	1.31	1.86	1.6	1.30	2.08
Lifting (15–25 kg)	1.5	1.38	1.68	1.2	1.11	1.31	1.4	1.27	1.51	1.5	1.36	1.73
Frequent bending	1.9	1.76	2.12	1.8	1.69	1.97	2.1	1.92	2.27	2.5	2.22	2.81

Proportional hazards model with five determinants in the model. Exposure variables lifting (>25 kg), twisted posture and noise omitted since they had 80% or more agreement with whole body vibration. Prevalence ratios (PR) and 95% CI).

symptoms in the neck, shoulder/arm and hand had the same or higher magnitude of association even when the possible confounders were in the model (Table 3). Females had 1.4–1.8 the risk of reporting musculoskeletal symptoms compared to men and frequent bending was approximately a two-fold risk for all the investigated musculoskeletal symptoms (Table 3).

The analysis indicated higher prevalence ratios for all the musculoskeletal symptoms the more of other exposure factors that were added to the risk model of combined exposure (Table 4). For the neck, low back and shoulder/arm there was a visible increase in prevalence ratio (as high as 5 times) as more other exposure factors were included in the risk model of combined exposure. Note that for symptoms in the hand there was 10 times the risk of reporting symptoms in the hand if exposed to all other exposure (WBV, lifting objects (light/heavy), frequent bending, twisted posture and noise) than of not being exposed. As an example if the prevalence ratios from the multivariate model of WBV (=1.4), lifting (15–25 kg) (=1.5) and frequent bending (=1.9) were multiplied from the multivariate analysis the result of 4.0 is similar to the 3.8 ratio obtained at the analysis of combined exposure factors (Tables 3 and 4).

5. Discussion

The main finding in this cross-sectional study was a strong relationship between WBV and symptoms in the neck, shoulder/arm and hand. The relationship between exposure to WBV and low back symptoms was of the same magnitude or lower when possible confounders were taken into account. Thus, the study shows the importance of considering ergonomic confounders when evaluating WBV exposure. Since we had to delete lifting (>25 kg), twisted posture and noise from the multivariate model due to 80% or more agreement between the exposure factors and WBV, the variable WBV in the multivariate model also contains these three

Table 4
Multivariate analysis of musculoskeletal symptoms in relation to risk combinations of ergonomic stressors and adjusted for gender and age (continuous)

Risk combination	Exposed (%)	Low back			Neck			Shoulder/arm			Hand		
		PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
Whole body vibration (3%) and lifting (15–25 kg) (24%)	1.4	2.8	2.18	3.55	2.3	1.80	2.84	3.2	2.62	4.00	4.4	3.37	5.82
Whole body vibration, lifting (15–25 kg) and frequent bending (37%)	1.04	3.8	2.94	5.03	3.1	2.4	4.00	4.9	3.89	6.25	7.5	5.52	10.15
Whole body vibration, lifting (15–25 kg), frequent bending and twisted posture (15%)	0.72	4.4	3.24	5.93	3.6	2.69	4.68	5.2	3.97	6.81	8.7	6.24	12.13
Whole body vibration, lifting (15–25 kg), frequent bending, twisted posture and noise	0.58	5.0	3.57	6.89	3.8	2.79	5.11	5.5	4.06	7.35	10.4	7.30	14.72
Whole body vibration and lifting (>25 kg) (14%)	0.97	2.8	2.16	3.68	2.2	1.69	2.83	3.0	2.38	3.80	4.7	3.56	6.20
Whole body vibration, lifting (>25 kg) and frequent bending	0.75	4.1	3.09	5.55	3.3	2.49	4.35	5.0	3.83	6.44	8.5	6.20	11.57
Whole body vibration, lifting (>25 kg), frequent bending and twisted posture	0.53	4.6	3.27	6.35	3.8	2.79	5.12	5.3	3.97	7.13	9.3	6.58	13.18
Whole body vibration, lifting (>25 kg), frequent bending, twisted posture and noise	0.47	5.0	3.53	7.11	3.9	2.79	5.34	5.4	3.93	7.40	10.8	7.56	15.51

The prevalence of the combinations of different stressors is given within parenthesis in percent (%) in the Swedish work force. In the exposed column the prevalence of exposed to the combination of risk factors are given in %. Proportional hazards model with 8 different combinations in the models. Prevalence ratios (PR) and 95% CI).

exposure variables. Exposure to WBV is often accompanied by exposure to manual material handling, and frequent bending. For the low back these ergonomic stressors seems more important than WBV for the relation to low back symptoms. This is consistent with the report from the UK [6].

The models with a combination of risk factors showed high prevalence ratios for pain in all the different musculoskeletal regions. High prevalence ratios indicate high attributable fractions and thus that preventive measure might be effective in reducing disorders [12]. When comparing the multivariate analysis with that of combined exposure adding a few factors gave similar result to the analysis of combined exposure. The lack of total correspondence between the multivariate and the combined factor analysis can be caused by the lack of precision in determining the prevalence ratios. The variability increased with more factors in the combination analysis due to smaller number of exposed cases. Furthermore, minor interactions between factors can add to the error.

Females had higher prevalence of musculoskeletal symptoms in all the studied regions compared to men even when controlling for age and other ergonomic exposure. This is consistent with other studies, for review see [13]. Whether there is a gender difference in health response to WBV is unclear [13].

5.1. Study considerations

The advantage with this study is that the study population is a representative sample of the Swedish work force. Furthermore we were able to study different ergonomic stressors besides WBV for musculoskeletal symptoms in different regions. The result of this cross-sectional study was based on self-report of both the outcome (musculoskeletal symptoms) and the exposure factors (work place factors and individual factors).

Thus, the study design limits causal inference. For example, the association may be a consequence, not a cause. Although the multivariate analyses showed that multiple factors had a stronger association with musculoskeletal symptoms, the impact on causality of cluster factors cannot be evaluated due to the study design.

The exposure categorization is based on self-report. The questions have been validated by Statistics Sweden and good validity of these questions has been found. The feasibility of exposure to WBV by questionnaire in the previous week was confirmed for 93% of subjects who reported exposure to WBV in a validity study by Palmer and co-workers and reported duration of exposure to WBV was generally accurate [14]. It was not possible to compute any dose measure or to define the diagnosis of different musculoskeletal disorders since our study was based on self reported survey data. We were not able to examine the separate effects of lifting (>25 kg), twisted posture and noise compared to WBV since there were 80% or more agreement between these exposure variables and WBVs.

6. Conclusions

It seems urgent to study the relation between WBV and musculoskeletal symptoms other than low back symptoms. In the present European directive WBV is associated with low back symptoms [2]. However, our investigation and other investigations have shown that other musculoskeletal symptoms may be linked more strongly to exposure to WBV. Thus, cohort studies of workers exposed to WBV are necessary to determine true risk ratios for WBV and different musculoskeletal symptoms. Possibly in the future there might be a need to revise the European directive on WBV to point out that health surveillance and clinical assessment should also include other regions than the low back.

Acknowledgment

This research is supported by the European Commission under the Framework 5 Quality of Life and Management of Living Resources programme—Project no. QLK4-2002-02650 (VIBRISKS).

References

[1] K.T. Palmer, M.J. Griffin, H. Bendall, B. Pannett, D. Coggon, Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey, *Journal of Occupational and Environmental Medicine* 57 (2000) 229–236.

[2] European Council, Directive 2002/44/EC of the European parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks rising from physical gents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), *Official Journal of the European Communities* L 177 (2002) 13–19.

[3] B.P. Bernard (Ed.), *Musculoskeletal Disorders and Workplace Factors*, National Institute for Occupational Safety and Health, Cincinnati, 1997.

[4] M. Bovenzi, C.T. Hulshof, An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986–1997), *International Archives of Occupational and Environmental Health* 72 (1999) 351–365.

[5] S. Lings, C. Leboeuf-Yde, Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992–1999, *International Archives of Occupational and Environmental Health* 73 (2000) 290–297.

[6] K.T. Palmer, M.J. Griffin, H.E. Syddall, B. Pannett, C. Cooper, D. Coggon, The relative importance of whole body vibration and occupational lifting as risk factors for low-back pain, *Journal of Occupational and Environmental Medicine* 60 (2003) 715–721.

[7] B. Rehn, I.A. Bergdahl, C. Ahlgren, C. From, B. Järvholm, R. Lundström, T. Nilsson, G. Sundelin, Musculoskeletal symptoms among drivers of all-terrain vehicles, *Journal of Sound and Vibration* 253 (2002) 21–29.

[8] Statistics Sweden, The work environment 2003. Report AM68SM0401 (www.av.se), 2004, pp. 1–227.

[9] SAS Institute Inc., SAS/STAT. *User's Guide*, version 8, 1999, pp. 1–3384.

[10] O. Axelsson, M. Fredriksson, K. Ekberg, Use of the prevalence ratio v the prevalence odds ratio in view of confounding in cross-sectional studies, *Journal of Occupational and Environmental Medicine* 52 (1995) 494–496.

[11] T.V. Perneger, What's wrong with Bonferroni adjustments, *British Medical Journal* 316 (1998) 1236–1238.

[12] J. Rothman, *Epidemiology: An Introduction*, Oxford University Press, Oxford, 2002 (pp. 1–223).

[13] W.E. Hooftman, M.N. van Poppel, A.J. van der Beek, P.M. Bongers, W. van Mechelen, Gender differences in the relations between work-related physical and psychosocial risk factors and musculoskeletal complaints, *Scandinavian Journal of Work Environment & Health* 30 (2004) 261–278.

[14] K.T. Palmer, B. Haward, M.J. Griffin, H. Bendall, D. Coggon, Validity of self reported occupational exposures to hand transmitted and whole body vibration, *Journal of Occupational and Environmental Medicine* 57 (2000) 237–241.