Available online at www.sciencedirect.com

ScienceDirect

Journal of Sound and Vibration 298 (2006) 514–539

JOURNAL OF SOUND AND VIBRATION

www.elsevier.com/locate/jsvi

An epidemiological study of low back pain in professional drivers

Massimo Bovenzi[a,*], Francesca Rui[a], Corrado Negro[a], Flavia D'Agostin[a], Giuliano Angotzi[b], Sandra Bianchi[b], Lucia Bramanti[b], GianLuca Festa[b], Silvana Gatti[b], Iole Pinto[b], Livia Rondina[b], Nicola Stacchini[b]

[a]*Unità Clinica Operativa di Medicina del Lavoro, Dipartimento di Scienze di Medicina Pubblica, Azienda Ospedaliero-Universitaria "Ospedali Riuniti di Trieste", Università di Trieste, Centro Tumori, Via della Pietà 19, I-34129 Trieste, Italy*

[b]*Departments of Prevention, National Health Service, Tuscany and Liguria Regions, Italy*

Received 29 April 2006; received in revised form 9 May 2006; accepted 8 June 2006

Available online 25 July 2006

Abstract

The prevalence of low back pain (LBP) was investigated in 598 Italian professional drivers exposed to whole-body vibration (WBV) and ergonomic risk factors (drivers of earth moving machines, fork-lift truck drivers, truck drivers, bus drivers). The control group consisted of a small sample of 30 fire inspectors not exposed to WBV. Personal, occupational and health histories were collected by means of a structured questionnaire. Vibration measurements were performed on representative samples of the machines and vehicles used by the driver groups. From the vibration magnitudes and exposure durations, alternative measures of vibration dose were estimated for each subject. Daily vibration exposure, expressed in terms of 8-h energy-equivalent frequency-weighted acceleration, $A(8)$, averaged 0.28–0.61 (range 0.10–1.18) $\mathrm{m\,s^{-2}}$ rms in the driver groups. Duration of exposure to WBV ranged between 1 and 41 years. The 7-day and 12-month prevalence of LBP was greater in the driver groups than in the controls. In the professional drivers, the occurrence of 12-month LBP, high intensity of LBP (Von Korff pain scale score $\geqslant 5$), and LBP disability (Roland & Morris disability scale score $\geqslant 12$) significantly increased with increasing cumulative vibration exposure. Even though several alternative measures of vibration exposure were associated with LBP outcomes, nevertheless a more regular trend of association with LBP was found for vibration dose expressed as $\sum a_{vi}t_i$ ($\mathrm{m\,s^{-2}\,h}$), in which the frequency-weighted acceleration, a_v, and lifetime exposure duration, t, were given equal weight. In multivariate data analysis, individual characteristics (e.g. age, body mass index) and a physical load index (derived from combining manual materials handling and awkward postures) were significantly associated with LBP outcomes, while psychosocial work factors (e.g. job decision, job support) showed a marginal relation to LBP. This study tends to confirm that professional driving in industry is associated with an increased risk of work-related LBP. Exposure to WBV and physical loading factors at work are important components of the multifactorial origin of LBP in professional drivers.

---

[*] Corresponding author. Tel.: +39 040 3992313; +39 040 632797; fax: +39-040-368199.
E-mail address: bovenzi@units.it (M. Bovenzi).

0022-460X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsv.2006.06.001

1. Introduction

Exposure to whole-body vibration (WBV) in professional drivers of industrial machines and/or vehicles is associated with an excess risk for back symptoms and disorders of the lumbar tract of the spine [1–5]. Reviews of the epidemiological literature have reported that the occurrence of low back pain and early degeneration of the lumbar spine, including intervertebral disc disorders, is greater in professional drivers than in control groups unexposed to WBV [6,7]. In a critical review of musculoskeletal disorders and workplace factors, investigators of the National Institute of Occupational Safety and Health (NIOSH, 1997) judged that after adjusting for potential confounders (e.g. age, smoking, physical and psychosocial work-related factors) there is strong evidence of a positive association between exposure to WBV and (low) back disorders [8].

The role of WBV in the aetiopathogenesis of low back disorders is not yet fully clarified, as driving of vehicles involves not only exposure to harmful WBV but also to several ergonomic risk factors which can affect the spinal system, such as prolonged sitting and awkward postures. Experimental studies have shown that WBV exposure, combined with a constrained sitting posture, can provoke failure of the lumbar intervertebral disc [9]. Moreover, some driving occupations involve heavy lifting and manual handling activities (e.g. drivers of delivery trucks), which are known to strain the lower part of the back. Individual characteristics (e.g. age, body mass, and smoking) and psychosocial factors are also suggested as potential predictors for low back pain [8,10,11]. It follows that injuries in the lower back of professional drivers may be considered as a complex of health disorders of multifactorial origin involving both occupational and non-occupational stressors.

Owing to the several factors potentially involved in the occurrence of low back pain, it is difficult to outline a clear exposure–response relationship between WBV exposure and low back disorders.

This cross-sectional survey represents the baseline investigation of a prospective cohort study of dose–response relationship for musculoskeletal symptoms in WBV-exposed drivers recruited in a 4-year research project entitled "*Risks of Occupational Vibration Injuries* (VIBRISKS)" and funded by the EU Commission.

VIBRISKS is a European research project which seeks to improve understanding of the risk of injury from occupational exposures to mechanical vibration by means of epidemiological studies supported by fundamental laboratory research [12]. Specific objectives of the project are: (i) to establish dose–response relationships between vibration exposures and injury; (ii) to investigate the interaction between vibration and other environmental, ergonomic and individual factors; (iii) to develop common methods for health surveillance; (iv) to improve methods for preventing disorders; and (v) to disseminate current knowledge on health surveillance and prevention to industry, occupational health professionals and end-users across Europe.

The aim of this study was to investigate the period prevalence of low back pain outcomes in various groups of Italian professional drivers. Vibration measurements were performed on a representative sample of the machines and vehicles used by the various driver groups. Finally, the association between low back disorders, WBV exposure, physical load factors, and psychosocial variables was investigated while controlling for potential individual confounders recognised as risk factors for low back pain.

2. Subjects and methods

2.1. Study population

The VIBRISKS project includes a work package devoted to epidemiological studies of the effects of WBV on musculoskeletal system. Researchers from four European countries are involved in WBV epidemiological work (Italy, Sweden, the Netherlands, United Kingdom). In Italy, the study population included 598 male professional drivers employed in several industries and public utilities located in Lucca, Massa Carrara, Siena, and Viareggio (Tuscany Region), Chiavari (Liguria Region), Modena (Emilia Romagna Region) and Trieste (Friuli Venezia Giulia Region).

Informed consent to the study was obtained from employers and employees at each company. As an incentive to participate in the study, a document providing a risk assessment for WBV exposure at workplace, according to article 4 of the EU Directive 2002/44/EC on mechanical vibration [13], was promised to the management and the representatives of workers at each company.

The WBV-exposed population included 110 drivers of earth moving machines and articulated trucks employed in marble quarries, 65 drivers of fork-lift trucks and mobile cranes employed in marble laboratories, 77 drivers of fork-lift trucks, container stake trucks and freight-container tractors employed in dockyards, 113 drivers of fork-lift trucks employed in paper mills, 62 drivers of garbage trucks, garbage compactors and track-type loaders employed in public utilities, and 171 bus drivers of mini-buses and city buses.

A minimum of 1 year of professional driving in current job was established as the basic criterion for the inclusion of drivers in the study population.

The rate of participation in the study was 92–97% for the drivers employed in the surveyed companies which were randomly selected among those sited in the provinces where the study was carried out.

The control group consisted of all fire inspectors employed at the Trieste dockyard (30 men), who had never been exposed to WBV at the workplace.

Table 1 reports the distribution of the study population by industry and machinery in Italy.

2.2. The questionnaire

The questionnaire used in this study was originally developed within the European Project *Vibration Injury Network* (VINET) [12]. The questionnaire has been undergoing a process of improving revisions on the basis of the findings of pilot studies and epidemiological surveys conducted across some European countries [14].

The questionnaire consisted of four major sections:

2.2.1. Personal and general information

The first section of the questionnaire included items on the subject's personal characteristics such as age, height, weight, education, marital status, physical activity or sport, smoking and drinking habits.

2.2.2. Occupational history

The second section of the questionnaire requested information on occupational history in the current and previous companies with details about job titles, duration of employment, types of machines or vehicles

Table 1
Distribution of the study population by industry and machinery in Italy

Industry	Number of drivers	Machine/vehicle
Marble quarries	110	Wheel loader Excavator Track-type loader Articulated truck Rock crusher Off-road car
Marble laboratories	65	Fork-lift truck Mobile crane
Dockyards	77	Container stake truck Fork-lift truck Freight-container tractor
Paper mills	113	Fork-lift truck
Public utilities (garbage)	62	Garbage truck Garbage compactor Track-type loader
Public transport (bus)	171	Minibus City bus

driven, daily and cumulative duration of driving on specific machine or vehicle, physical load during an average working day (walking and standing, sitting, non-neutral postures, digging, lifting), and aspects related to psychosocial factors at work (job decision, job support from supervisors or co-workers, job satisfaction). Work-related physical load was graded by rating the frequency and/or the duration of manual activities during a typical working day. Job decision and job support were measured on a 4-point scale (“never/almost never”, “seldom”, “sometimes”, “often”), as well as job satisfaction (“very dissatisfied”, “dissatisfied”, “satisfied”, “very satisfied”).

2.2.3. *Personal medical history*

The third section of the questionnaire focused on health complaints which were investigated using a modified version of the Nordic questionnaire on musculoskeletal symptoms [15]. The workers were questioned on the occurrence of neck, shoulder, and low back pain (LBP) in the last 7 days and the last 12 months. Workers who reported musculoskeletal symptoms were requested to answer to additional questions concerning duration, frequency, pain radiation, pain intensity and disability, health care use because of symptoms, treatment (e.g. anti-inflammatory drugs or physical therapy), and sick leave due to symptoms in the previous 7 days and 12 months. Pain intensity was rated on a 11-point scale, where 0 is “no pain at all” and 10 is “pain as bad as it could be” according to the pain scale proposed by Von Korff et al. [16]. Disability due to the last episode of LBP was measured by means of the Roland & Morris disability scale [17]. The workers were requested to answer 24 questions concerning daily life activities which were impaired by LBP, such as standing up, walking, bending, getting dressed, getting out of a chair, etc. A disability scale score for each worker suffering from LBP was obtained by summing up the number of disability conditions experienced by the affected worker.

2.2.4. *Other symptoms and feelings*

The fourth section of the questionnaire contained items on musculoskeletal symptoms in the upper and lower extremities, other health disorders, and psychological feelings of workers about their life conditions and the consequences of LBP on their health status and work activity.

Workers were interviewed by certified occupational health personnel who were trained to conduct the interview in a standardised way. For this purpose, specific meetings were organised to test the method of administration of the questionnaire to workers.

2.3. *Definition of LBP outcomes*

On the basis of the items included in the medical section of the questionnaire, LBP outcomes were defined as follows:

(i) LBP: pain or discomfort in the low back area between the twelfth ribs and the gluteal folds (indicated in a figure), with or without radiating pain in one or both legs, lasting one day or longer in the previous seven days (7-day LBP) or the previous twelve months (12-month LBP).
(ii) High pain intensity: LBP in the previous 12 months associated with a pain score $\geqslant 5$ (Von Korff scale).
(iii) LBP disability: last episode of LBP associated with a disability score $\geqslant 12$ (Roland & Morris scale).

2.4. *Measurement and assessment of vibration exposure*

Vibration measurements were made on representative samples of industrial machines and vehicles ($n = 74$) used by the professional drivers. Vibration was measured at the driver–seat interface during actual operating conditions according to the recommendations of the International Standard ISO 2631-1 [18].

2.4.1. *Calculation of vibration total value*

From one-third-octave band frequency spectra (1–80 Hz) recorded from x-, y-, and z-directions, frequency-weighted root-mean-square (rms) accelerations (a_{wx}, a_{wy}, a_{wz}) were obtained by using the weighting factors suggested by ISO 2631-1. The vibration total value (or vector sum) of the weighted rms accelerations, a_v, was calculated according to the following formula:

$$a_v = \left[(1.4a_{wx})^2 + (1.4a_{wy})^2 + a_{wz}^2\right]^{1/2} \quad (\mathrm{ms^{-2}\,rms}). \tag{1}$$

2.4.2. *Calculation of daily vibration exposure*

For each operator, questionnaire data and company records were used to estimate daily exposure to WBV expressed in driving hours, as well as the total duration of exposure to WBV in full-time driving years.

Daily vibration exposure was expressed in terms of 8-h energy-equivalent frequency-weighted acceleration magnitude ($A(8)$) according to the EU Directive on mechanical vibration [13]:

$$A(8) = a_w(T/T_0)^{1/2}(\mathrm{ms^{-2}\,rms}), \tag{2}$$

where T is the total daily duration of exposure to the vibration a_w, and T_0 is a reference duration of 8 h.

In Eq. (2), a_w was included as either a_v ($A_v(8)$), or the highest (dominant) value of the frequency-weighted rms accelerations determined on the three orthogonal axes ($A_{\mathrm{dom}}(8)$), as required by the EU Directive [13].

2.4.3. *Calculation of measures of cumulative vibration dose*

Vibration total value and duration of exposure were used to construct measures of cumulative vibration dose estimated as

$$\mathrm{dose} = \sum_i \left[a_i^m t_i\right], \tag{3}$$

where a_i is the vibration total value of the frequency-weighted accelerations measured on machine i driven for time t_i in hours (h/d × d/year × years).

In these doses, the relative importance of the frequency-weighted acceleration, a, and the total exposure duration, t, depends on the value of m. If m has the value 2, the relationship between a and t is that assumed in rms averaging (as suggested in current standards to evaluate vibration exposure over a working day). Assigning values of 1 or 4 to m decreases or increases, respectively, the 'importance' of the vibration magnitude, a, relative to that of exposure duration, t. With $m = 0$, the dose takes no account of vibration magnitude. Doses with $m = 0$, 1, 2, and 4 were computed for each driver.

2.5. *Assessment of physical load*

A combined approach consisting of both direct observation of working conditions and the subject's self-assessment during the interview was used to evaluate physical load in the controls and the professional drivers. Photos and videos were taken at the workplace to analyse drivers' postures during a working day.

Heavy physical work was graded by rating the frequency of manual activities on a 3-point response scale (e.g. lifting loads > 15 kg with trunk bent and twisted: "not at all", "1–10 times", "more than 10 times"). Awkward postures were graded by rating the duration of each posture on a 4-point time scale (e.g. working with trunk bent > 40°: "never", "less than 1 h", "1–2 h", "more than 2 h"). A mean value of physical load variables during a typical working day was calculated for each subject. In the total sample, the average physical load index was divided into quartiles (q) which were assumed to correspond to four grades of increasing physical load: 1st q = mild load grade, 2nd q = moderate load grade, 3rd q = hard load grade, 4th q = very hard load grade.

2.6. *Data analysis*

The statistical analysis of data was performed with the Stata software, version 8.2 (Stata Corporation, 2004).

Continuous variables were summarised with the mean as a measure of central tendency and the standard deviation (SD) as a measure of dispersion.

The difference between two or more than two means was tested with Student's *t*-test or one-way analysis of variance (ANOVA), respectively. The difference between categorical data cross-tabulated into contingency tables was tested by χ^2 statistic.

The association between LBP outcomes and several independent variables was assessed by unconditional logistic regression analysis. Odds ratios (OR) and 95% confidence intervals (95% CI) were estimated from the logistic regression coefficients and their standard errors. When data were very sparse, a median unbiased estimate of the odds ratio and 95% exact confidence interval for the odds ratio were obtained by means of exact logistic regression methods provided by the LogXact software, version 6 (Cytel Corporation, 2004).

Initially, univariate associations were examined to study the effect of various predictors on the occurrence of low back complaints. Then, multivariate logistic regression models were used to assess the association between LBP outcomes and exposure variables (vibration and physical load) while controlling for the influence of personal and psychosocial factors. Both exposure variables and confounding factors entered in the logistic model as categorical covariates, except for age, which was used as a continuous covariate. The significance of additional variables in the model was tested by the likelihood ratio (LR) χ^2 statistic. Independent variables were retained in the model when their probability value was <0.25. Age was included in each model regardless of the level of statistical significance. The magnitude of the LR statistic was used to assess the "importance", in statistical terms, of the alternative measures of vibration exposure for the prediction of the outcome. The goodness of fit of the logistic models was assessed by the Hosmer–Lemeshow χ^2 statistic [19].

3. Results

3.1. Vibration measurements

Table 2 reports the mean (SD) values of the frequency-weighted rms accelerations measured at the driver–seat interfaces on the machines and vehicles used by the professional drivers. The *z*-axis (vertical) weighted acceleration was the dominant directional component of vibration measured in most of the machines and vehicles. In marble quarries, the vibration total value (a_v) of the weighted rms accelerations averaged 0.57–0.69 $\mathrm{m\,s^{-2}}$ rms in earth moving machines and 0.5–1.1 $\mathrm{m\,s^{-2}}$ rms in transport vehicles. The lowest a_v values were measured on garbage machines (0.29–0.31 $\mathrm{m\,s^{-2}}$ rms) and on mobile cranes used in marble laboratories (0.32 $\mathrm{m\,s^{-2}}$ rms). Vibration from buses varied from 0.51 (minibus) to 0.61 $\mathrm{m\,s^{-2}}$ rms (city bus). The average a_v measured on fork-lift trucks used in marble laboratories was two to three times greater (1.1 $\mathrm{m\,s^{-2}}$ rms) than those measured on fork-lift trucks driven in dockyards (0.54 $\mathrm{m\,s^{-2}}$ rms) and paper mills (0.36 $\mathrm{m\,s^{-2}}$ rms). This finding may be ascribed to differences in vehicle design and power, items to be lifted, operating conditions, and seat quality between the fork-lift trucks used in the various industries.

Frequency analysis showed that the vibration frequencies with the highest rms accelerations were 1.25–5 Hz (*z*-axis) for most of the machines, with additional acceleration peaks at 8 and 16 Hz in the excavators and fork-lift trucks.

3.2. Characteristics of the study groups

Preliminary data analysis showed significant differences between the several study groups with respect to age, smoking habit, and level of education (Table 3). Marginal, even though significant, differences were observed for anthropometric characteristics and regular physical activity ($p<0.05$). Drinking habit and marital status did not differ between groups.

The distribution of previous jobs with heavy physical demands was similar in the various groups (results not shown).

An ergonomic checklist compiled at the workplaces showed that heavy physical work and non-neutral postures others than when driving, were more frequent in the professional drivers than in the controls.

In the controls, both dynamic and static postures were observed. Their workshift included 50–60% walking and standing, and 30–40% sitting. Activities involving non-neutral trunk postures accounted for less than 5–10% in a typical workshift.

Table 2
Frequency-weighted root-mean-square (rms) acceleration magnitude (a_w) of vibration measured in the x-, y-, and z-directions on the seat of industrial machines and vehicles. The vibration total value of frequency-weighted rms accelerations (a_v) is calculated according to International Standard ISO 2631-1 (1997). Data are given as means (standard deviations)

Machine/vehicle	Sector	Number of vehicles measured	Frequency-weighted acceleration magnitude			
			a_{wx} (m s^{-2} rms)	a_{wy} (m s^{-2} rms)	a_{wz} (m s^{-2} rms)	a_v (m s^{-2} rms)
Wheel loader	Marble quarries	6	0.21 (0.04)	0.25 (0.06)	0.35 (0.09)	0.57 (0.11)
Excavator	Marble quarries	4	0.24 (0.10)	0.20 (0.10)	0.52 (0.11)	0.69 (0.19)
Rock crusher	Marble quarries	1	0.07 (0.01)	0.07 (0.02)	0.66 (0.07)	0.67 (0.12)
Articulated truck	Marble quarries	1	0.14 (0.04)	0.18 (0.10)	0.38 (0.12)	0.50 (0.15)
Off-road car	Marble quarries	1	0.33 (0.08)	0.38 (0.09)	0.85 (0.10)	1.1 (0.11)
Mobile crane	Marble laboratories	5	0.06 (0.01)	0.07 (0.02)	0.29 (0.06)	0.32 (0.06)
Fork-lift truck	Marble laboratories	5	0.30 (0.03)	0.28 (0.07)	0.95 (0.12)	1.1 (0.10)
Fork-lift truck	Paper mill	8	0.11 (0.02)	0.11 (0.02)	0.28 (0.05)	0.36 (0.04)
Fork-lift truck	Dockyard	8	0.20 (0.08)	0.15 (0.06)	0.40 (0.14)	0.54 (0.17)
Track-type loader	Dockyard	3	0.29 (0.15)	0.30 (0.15)	0.49 (0.26)	0.76 (0.39)
Freight-container tractor	Dockyard	1	0.16 (0.01)	0.21 (0.01)	0.57 (0.03)	0.68 (0.03)
Garbage truck	Public utilities	5	0.10 (0.02)	0.10 (0.02)	0.24 (0.03)	0.31 (0.03)
Garbage compactor	Public utilities	1	0.08 (0.02)	0.12 (0.06)	0.21 (0.02)	0.29 (0.05)
Minibus	Public utilities	12	0.12 (0.03)	0.27 (0.04)	0.39 (0.10)	0.61 (0.13)
City bus	Public utilities	13	0.13 (0.05)	0.13 (0.05)	0.43 (0.10)	0.51 (0.12)

There were significant differences in vibration exposure between the driver groups (Table 4). Total duration of exposure to WBV in either full-time driving years or total driving hours were significantly greater in bus drivers and drivers employed in marble quarries and paper mills compared with the other groups. Daily vibration exposure in terms of $A_v(8)$ ranged from 0.28 (drivers of garbage machines) to 0.61 m s^{-2} rms (drivers of earth moving machines), ($p<0.001$). It should be noted that when daily vibration exposure was expressed as $A_{\text{dom}}(8)$ according to the EU Directive on mechanical vibration [13], no driver group exceeded, on average, the daily exposure action value established by the Directive (0.5 m s^{-2} rms). Vibration doses estimated as $\sum[a_{vi}{}^{m}t_i]$ were significantly higher in the drivers of earth moving machines (marble quarries), fork-lift trucks (marble laboratories) and buses than in the other driver groups ($p<0.001$).

Previous jobs with WBV exposure were more frequently reported by drivers employed in public utilities ($p<0.01$).

3.3. Low back pain and individual, occupational, and psychosocial variables

3.3.1. Individual variables

Univariate analysis showed that in the overall study population LBP outcomes were significantly associated with age (Table 5). After adjustment for age, there were no clear associations between LBP outcomes and smoking, education, and regular sport activity. Drinking habit was marginally related to pain intensity and disability. The occurrence of LBP tended to increase with increasing body mass index (BMI), but a significant association was found only between LBP disability and overweight (BMI$>$27).

3.3.2. Occupational variables

The various LBP outcomes were significantly associated with current driving occupation and previous jobs with WBV exposure, while no relation was found with previous jobs with heavy physical demands (Table 5). Overall, work-related physical load factors, treated as dichotomous variables, were positively related to LBP outcomes. Awkward postures at work, such as trunk bending and twisting while lifting loads, showed highly significant associations with 12-month LBP, pain intensity and disability. Back trauma was a predictor of the

Table 3
Characteristics of the study populations. Data are given as means (standard deviations) for age and anthropometric characteristics, or as numbers (%) for smoking, drinking, marital status, education and physical activity

	Controls ($n = 30$)	Drivers					
		Marble quarries ($n = 110$)	Marble laboratories ($n = 65$)	Dockyards ($n = 77$)	Paper mills ($n = 113$)	Public utilities (garbage) ($n = 62$)	Public utilities (bus) ($n = 171$)
Age (years)	37.0 (8.2)	41.0 (8.5)	40.7 (9.6)	37.5 (7.8)	41.8 (8.1)	42.2 (8.3)	43.6 (6.6)^b
Height (cm)	177 (5.6)	177 (7.0)	175 (6.6)	178 (6.9)	175 (6.9)	175 (7.9)	177 (6.4)^a
Weight (kg)	79.7 (13.0)	83.3 (12.9)	83.0 (18.5)	81.5 (11.5)	79.0 (12.1)	84.2 (15.2)	83.3 (11.2)
Body mass index (kg/m^2)	25.4 (3.7)	26.7 (3.6)	27.1 (5.4)	25.7 (3.4)	25.7 (3.4)	27.5 (4.0)	26.6 (3.2)^a
Smoking (*n*):							
Never	6 (20.0)	48 (43.6)	23 (35.4)	22 (28.6)	45 (39.8)	19 (30.6)	94 (55.0)
Ex-smokers	6 (20.0)	27 (24.6)	16 (24.6)	10 (13.0)	26 (23.0)	22 (35.5)	33 (19.3)
Current smokers	18 (60.0)	35 (31.8)	26 (40.0)	45 (58.4)	42 (37.2)	21 (33.9)	44 (25.7)^d
Drinking (*n*)	19 (63.3)	75 (68.2)	50 (76.9)	51 (66.2)	75 (66.4)	46 (74.2)	98 (57.3)
Married (*n*)	13 (43.3)	84 (76.4)	52 (80.0)	41 (53.3)	82 (72.6)	50 (80.7)	123 (71.9)
Education (*n*):							
$\leqslant$6 years	1 (3.3)	9 (8.2)	7 (10.8)	2 (2.6)	18 (15.9)	6 (9.7)	9 (5.3)
7–12 years	19 (63.3)	75 (68.2)	48 (73.8)	59 (76.6)	55 (48.7)	51 (82.3)	117 (68.4)
$>$12 years	10 (33.3)	26 (23.6)	10 (15.4)	16 (20.8)	40 (35.4)	5 (8.0)	45 (26.3)^d
Physical activity (*n*):							
Never	19 (63.3)	58 (52.7)	45 (69.2)	37 (48.1)	56 (49.5)	28 (45.2)	57 (33.3)
$<$1 per week	3 (10.0)	11 (10.0)	2 (3.1)	6 (7.8)	9 (8.0)	9 (14.5)	30 (17.5)
1–2 per week	3 (10.0)	27 (24.6)	11 (16.9)	17 (22.1)	27 (23.9)	12 (19.3)	49 (28.7)
$\geqslant$3 per week	5 (16.7)	14 (12.7)	7 (10.8)	17 (22.1)	21 (18.6)	13 (21.0)	25 (20.5)^c

F-test (one-way ANOVA): $^a p<0.05$; $^b p<0.001$.
χ^2-test: $^c p<0.05$; $^d p<0.01$.

Table 4

Measures of exposure to whole-body vibration (WBV) in the professional drivers (see text, Section 2.4., for definitions of WBV exposure). Data are given as means (standard deviations). Previous jobs with WBV exposure are given as numbers (%)

Measures of vibration exposure	Drivers					
	Marble quarries ($n = 110$)	Marble laboratories ($n = 65$)	Dockyards ($n = 77$)	Paper mills ($n = 113$)	Public utilities (garbage) ($n = 62$)	Public utilities (bus) ($n = 171$)
Daily driving time (h)	5.7 (2.6)	4.4 (2.9)	6.3 (0.9)	6.4 (1.9)	5.5 (0.8)	6.0 (0.8)[a]
A_v (8) ($\mathrm{m\,s^{-2}\,rms}$)	0.61 (0.18)	0.47 (0.26)	0.55 (0.06)	0.32 (0.06)	0.29 (0.06)	0.48 (0.04)[a]
A_{dom} (8) ($\mathrm{m\,s^{-2}\,rms}$)	0.41 (0.12)	0.40 (0.22)	0.44 (0.07)	0.25 (0.04)	0.23 (0.07)	0.41 (0.04)[a]
Duration of exposure in current job (years)	14.9 (9.8)	13.5 (8.8)	8.4 (7.6)	12.5 (8.7)	7.9 (6.1)	16.1 (8.5)[a]
$\sum[t_i]$ ($\mathrm{h} \times 10^3$)	19.4 (16.6)	13.5 (13.2)	12.1 (11.6)	18.2 (14.1)	9.3 (7.0)	21.6 (11.7)[a]
$\sum[a_{vi}t_i]$ ($\mathrm{m\,s^{-2}\,h} \times 10^3$)	14.5 (12.7)	8.9 (10.4)	7.1 (6.4)	6.5 (5.1)	3.0 (2.1)	12.1 (6.5)[a]
$\sum[a_{vi}{}^2t_i]$ ($\mathrm{m^2\,s^{-4}\,h} \times 10^3$)	11.0 (9.9)	7.2 (10.6)	4.2 (3.6)	2.4 (1.8)	1.0 (0.6)	6.7 (3.6)[a]
$\sum[a_{vi}{}^4t_i]$ ($\mathrm{m^4\,s^{-8}\,h} \times 10^3$)	6.7 (6.6)	6.5 (12.8)	1.5 (1.3)	0.31 (0.24)	0.12 (0.08)	2.1 (1.2)[a]
Previous jobs with WBV exposure (n)	29 (26.4)	18 (27.7)	15 (19.5)	36 (31.9)	44 (70.9)	95 (55.6)[b]

F-test (one-way ANOVA): [a]$p<0.001$; χ^2-test: [b]$p<0.01$.

Table 5
Age-adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for 7-day low back pain (LBP), 12-month LBP, high pain intensity in the lower back (Von Korff pain scale score ⩾5) during the previous 12 months, and disability (Roland & Morris disability scale score ⩾12) during the last episode of LBP in the total population ($n = 628$) according to various individual and work-related risk factors

Factors	7-day LBP OR (95% CI)	12-month LBP OR (95% CI)	High pain intensity OR (95% CI)	LBP disability OR (95% CI)
Age (years)				
⩽37	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
38–45	2.17 (1.36–3.46)	1.80 (1.21–2.67)	1.72 (1.15–2.55)	2.02 (1.12–3.63)
>45	2.24 (1.39–3.60)	1.10 (0.75–1.64)	1.19 (0.78–1.79)	2.10 (1.16–3.81)
Occupation				
Sedentary	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Driving	4.49 (1.05–19.2)	2.81 (1.31–6.04)	2.35 (0.94–5.86)	7.73[a] (1.36–+∞)[b]
BMI (kg/m^2)				
<25	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
25–27	1.16 (0.74–1.82)	1.02 (0.68–1.51)	0.99 (0.66–1.50)	1.02 (0.55–1.87)
>27	1.02 (0.64–1.62)	1.45 (0.96–2.18)	1.49 (0.99–2.25)	1.86 (1.05–3.27)
Smoking				
No smoking	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Ex-smoker	0.78 (0.49–1.25)	0.85 (0.55–1.32)	0.85 (0.55–1.32)	0.88 (0.49–1.56)
Current smoker	0.60 (0.39–0.91)	0.79 (0.55–1.13)	0.76 (0.52–1.10)	0.84 (0.50–1.40)
Drinking				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	0.89 (0.61–1.30)	1.24 (0.88–1.74)	1.42 (1.00–2.03)	1.70 (1.02–2.84)
Education (years)				
⩽6	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
7–12	0.79 (0.42–1.51)	1.13 (0.61–2.09)	1.24 (0.65–2.35)	1.08 (0.48–2.43)
>12	0.66 (0.32–1.36)	1.19 (0.60–2.35)	1.18 (0.58–2.39)	1.23 (0.50–3.03)
Regular sport activity				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	1.07 (0.74–1.54)	0.98(0.70–1.35)	1.18 (0.85–1.64)	1.27 (0.81–1.99)
Previous jobs with WBV exposure				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	1.56 (1.08–2.24)	1.40 (1.00–1.96)	1.45 (1.04–2.03)	1.37 (0.88–2.15)
Previous job with heavy physical load				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	0.79 (0.50–1.24)	1.04 (0.71–1.54)	1.14 (0.77–1.68)	0.82 (0.46–1.44)
Trunk bent at work				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	0.85 (0.56–1.29)	1.83 (1.24–2.72)	1.67 (1.16–2.42)	1.82 (1.14–2.90)
Trunk bent & twisted at work				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	0.99 (0.64–1.51)	1.40 (0.94–2.08)	1.16 (0.79–1.70)	1.12 (0.68–1.86)
Lifting at work				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	0.71 (0.46–1.07)	1.29 (0.89–1.87)	0.89 (0.62–1.29)	1.80 (1.13–2.86)
Lifting & bending at work				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	0.74 (0.48–1.14)	1.50 (1.00–2.24)	1.24 (0.85–1.81)	2.41 (1.49–3.88)
Lifting & twisting at work				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	1.04 (0.65–1.66)	1.90 (1.18–3.07)	1.57 (1.02–2.41)	3.65 (2.20–6.08)

Table 5 (*continued*)

Factors	7-day LBP OR (95% CI)	12-month LBP OR (95% CI)	High pain intensity OR (95% CI)	LBP disability OR (95% CI)
Back bent forward or twisted while driving				
No	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Yes	2.75 (1.59–4.76)	2.19 (1.49–3.23)	1.66 (1.09–2.53)	1.69 (0.91–3.16)

[a] Median unbiased estimate.

[b] Exact 95% confidence interval.

Table 6

Age-adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for 7-day low back pain (LBP), 12-month LBP, high pain intensity in the lower back (Von Korff pain scale score $\geqslant 5$) during the previous 12 months, and disability (Roland & Morris disability scale score $\geqslant 12$) during the last episode of LBP in the total population ($n = 628$) according to psychosocial factors

Factor	7-day LBP OR (95% CI)	12-month LBP OR (95% CI)	High pain intensity OR (95% CI)	LBP disability OR (95% CI)
Job decision				
(i) how to do your work				
Often	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Sometimes	0.90 (0.49–1.66)	0.70 (0.41–1.18)	0.73 (0.43–1.26)	0.53 (0.26–1.09)
Seldom	1.95 (0.93–4.05)	0.95 (0.45–1.97)	0.83 (0.40–1.72)	0.59 (0.23–1.51)
Never/almost never	1.63 (1.00–2.67)	1.14 (0.70–1.84)	1.03 (0.65–1.63)	0.57 (0.32–1.04)
(ii) what to do at work				
Often	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Sometimes	0.80 (0.39–1.64)	1.01 (0.55–1.83)	1.01 (0.56–1.83)	0.31 (0.12–0.78)
Seldom	0.85 (0.36–2.03)	0.59 (0.29–1.22)	0.51 (0.23–1.16)	0.82 (0.35–1.95)
Never/almost never	1.75 (1.09–2.82)	1.23 (0.79–1.94)	1.08 (0.70–1.67)	0.59 (0.34–1.00)
(iii) timetable & breaks				
Often	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Sometimes	0.95 (0.46–1.94)	1.27 (0.69–2.31)	1.23 (0.67–2.27)	1.48 (0.69–3.15)
Seldom	1.34 (0.57–3.11)	1.15 (0.54–2.43)	1.37 (0.64–2.90)	1.53 (0.61–3.82)
Never/almost never	1.73 (0.96–3.10)	1.75 (1.05–2.94)	1.18 (0.70–1.99)	1.03 (0.53–2.03)
Job support				
Often	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Sometimes	1.47 (0.92–2.35)	1.16 (0.73–1.82)	0.92 (0.59–1.44)	0.91 (0.52–1.58)
Seldom	2.72 (1.12–6.63)	1.51 (0.57–3.98)	1.97 (0.82–4.71)	1.64 (0.61–4.41)
Never	1.66 (0.47–5.90)	0.99 (0.28–3.46)	1.96 (0.58–6.60)	0.39 (0.05–3.14)
Job satisfaction				
Very satisfied	1.0 (–)	1.0 (–)	1.0 (–)	1.0 (–)
Satisfied	1.11 (0.72–1.69)	0.91 (0.62–1.33)	1.07 (0.73–1.58)	0.67 (0.41–1.11)
Dissatisfied	1.72 (0.94–3.12)	1.00 (0.56–1.77)	1.44 (0.82–2.54)	0.96 (0.47–1.98)
Very dissatisfied	0.40 (0.05–3.39)	0.95 (0.22–4.13)	0.27 (0.03–2.21)	0.59 (0.07–5.00)

occurrence of LBP in the last 7 days (age-adjusted OR: 2.05; 95% CI: 1.06–3.97) and of high pain intensity in the previous 12 months (age-adjusted OR: 1.95; 95% CI: 1.03–3.68). Back trauma was also associated, even though not significantly, with an excess risk for LBP disability (age-adjusted OR: 1.80; 95% CI: 0.82–3.93).

3.3.3. *Psychosocial variables*

No clear pattern of association between LBP and psychosocial factors at work was observed in the study population (Table 6). Only LBP in the last 7 days showed a marginally significant association with job decision and job support at work from supervisors and co-workers. Positive psychological feelings were inversely

Table 7

Age-adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for 7-day low back pain (LBP), 12-month LBP, high pain intensity in the lower back (Von Korff pain scale score $\geqslant 5$) during the previous 12 months, and disability (Roland & Morris disability scale score $\geqslant 12$) during the last episode of LBP in the various groups of professional drivers, assuming the controls as the reference category. The prevalence of LBP outcomes is also given

Outcome	Controls ($n = 30$)	Drivers					
		Marble quarries ($n = 110$)	Marble laboratories ($n = 65$)	Dockyards ($n = 77$)	Paper mills ($n = 113$)	Public utilities (garbage) ($n = 62$)	Public utilities (bus) ($n = 171$)
7-day LBP (%)	6.7	15.5	6.2	26.0	27.4	25.8	42.1
OR	1.0	2.30	0.82	4.90	4.70	4.27	8.68
(95% CI)	(–)	(0.50–10.6)	(0.14–4.79)	(1.07–22.5)	(1.05–21.0)	(0.91–20.1)	(1.99–37.9)
12-month LBP (%)	36.7	58.2	55.4	53.3	62.8	61.3	71.4
OR	1.0	2.45	2.18	1.97	2.98	2.80	4.43
(95% CI)	(–)	(1.06–5.66)	(0.89–5.32)	(0.83–4.69)	(1.29–6.91)	(1.13–6.94)	(1.94-10.1)
High pain intensity (%)	20	40.9	20.0	29.9	42.5	48.4	36.3
OR	1.0	2.82	1.02	1.71	3.01	3.83	2.34
(95% CI)	(–)	(1.06–7.48)	(0.34–3.00)	(0.62–4.73)	(1.14–7.99)	(1.37–10.7)	(0.90-6.10)
LBP disability (%)	0	22.7	18.5	15.6	12.4	12.9	12.3
OR	1.0	12.2^{a}	9.20^{a}	7.53^{a}	5.83^{a}	5.94^{a}	5.85^{a}
(95% CI)	(–)	$(2.04\text{–}+\infty)^{b}$	$(1.43\text{–}+\infty)^{b}$	$(1.18\text{–}+\infty)^{b}$	$(0.93\text{–}+\infty)^{b}$	$(0.87\text{–}+\infty)^{b}$	$(0.97\text{–}+\infty)^{b}$

[a] Median unbiased estimate.

[b] Exact 95% confidence interval.

related, even though not significantly, to the occurrence of LBP, while negative feelings were associated with an increased risk for LBP outcomes (results not shown).

3.3.4. Health outcomes

Table 7 reports the prevalence of LBP and the risk estimates for LBP outcomes in the study population. Almost all driver groups showed a greater period prevalence of LBP compared with the controls. Significantly increased ORs for high pain intensity were found in the drivers employed in marble quarries, paper mills and public utilities. LBP disability was more frequently reported by drivers working in the marble industry and dockyards. It should be noted that none of the controls complained about LBP disability according to the definition adopted in this study. Hence, the median unbiased estimates of the odds ratio for LBP disability reported in Table 7 should be interpreted with caution because their predictive performance is not very well known, while the exact 95% CI are more reliable for inference [20].

In the last 12 months, duration of LBP was longer ($p<0.05$) and health care use for LBP was more frequent ($p<0.01$) in the drivers than in the controls (Table 8). The number of episodes of LBP and sick leave due to LBP in the last 12 months were also more frequent in the drivers compared with the controls, but the difference was not significant.

3.4. Low back pain and vibration exposure

To assess possible exposure–response relationship for LBP outcomes in the professional drivers, measures of vibration exposure such as ($A(8)$), duration of exposure in years, and vibration doses of the form $\sum[a_{vi}{}^{m}t_i]$, were divided into quartiles assuming the lowest quartile as the reference category.

Figs. 1–3 display the crude prevalence of 12-month LBP, high pain intensity, and LBP disability, respectively, by quartiles of measures of vibration exposure. Test for trend showed a pattern of increasing prevalence of LBP outcomes with the increase of vibration exposure expressed in terms of $\sum[t_i]$, $\sum[a_{vi}t_i]$, or $\sum[a_{vi}{}^{2}t_i]$, ($p<0.005$). A significant trend for 12-month LBP and LBP disability, but not for high pain intensity, was observed when vibration exposure was expressed as full-time driving years or $\sum[a_{vi}{}^{4}t_i]$, ($0.005<p<0.05$). No significant trend was found for daily vibration exposure ($A_v(8)$), ($p>0.1$).

These findings were confirmed by multivariate logistic regression analysis in which the set of independent variables included, in addition to vibration exposure, potential confounders such as personal characteristics (e.g. age, BMI), physical load factors and psychosocial variables (Tables 9–11). To investigate exposure–response relationships, the controls were excluded from data analysis.

The likelihood ratio test showed that vibration doses $\sum[t_i]$ and $\sum[a_{vi}t_i]$ were significant predictors of all LBP outcomes, i.e. 12-month LBP, high pain intensity, and LBP disability. The occurrence of 12-month LBP and LBP disability was associated with $\sum[a_{vi}{}^{2}t_i]$. High pain intensity and LBP disability were significantly related to exposure duration (year) and $\sum[a_{vi}{}^{4}t_i]$, respectively. None of the various LBP outcomes was associated with daily vibration exposure, $A(8)$. Trend statistics showed similar results when the measures of vibration exposure were included as continuous variables in the logistic models. The Hosmer–Lemeshow test showed that the goodness of fit was good, or at least acceptable, for all logistic models.

3.5. Low back pain and other physical load factors

Owing to differences in the frequency and duration of awkward postures at work between the various driver groups, no specific posture showed an evident trend of association with LBP outcomes (Table 12).

Walking and standing at work, as well as sitting more than 3 h/d other than when driving (age-adjusted OR: 0.53; 95% CI: 0.25–1.12), were not related to any LBP outcome.

After adjustment for potential confounders, the likelihood ratio statistic showed that the occurrence of LBP in the last 12 months was significantly associated with working with trunk bent 20–40° and with driving with back bent forward or twisted. Moreover, bending forward 20–40° or more than 40° was predictive for LBP disability. Nevertheless, the adjusted ORs for the highest category of these postural variables were not significantly increased. This finding may be due, at least partially, to the limited number of subjects included in the highest category of postural load variables.

Table 8
Number of episodes of low back pain (LBP), duration of LBP, health care use and sick leave because of LBP during the previous 12 months in the controls and the professional drivers. Data are given as percentages

Outcome	Controls ($n = 30$)	Drivers					
		Marble quarries ($n = 110$)	Marble laboratories ($n = 65$)	Dockyards ($n = 77$)	Paper mills ($n = 113$)	Public utilities (garbage) ($n = 62$)	Public utilities (bus) ($n = 171$)
Episodes of LBP (n)							
1	6.7	11.4	10.0	5.9	9.7	8.1	12.4
2–5	10.0	21.1	25.0	25.0	30.6	16.1	23.6
6–10	10.0	5.5	6.3	7.9	6.3	11.3	14.3
>10	10.0	20.2	14.1	14.5	16.2	25.8	21.1
Duration of LBP[a]							
Hours	22.4	15.5	15.2	6.7	13.3	14.5	17.9
1–2 days	3.6	11.1	12.9	23.3	25.7	8.1	18.5
3–6 days	7.1	23.2	17.7	15.1	13.3	22.6	15.2
7–30 days	3.6	2.8	4.8	2.7	2.9	6.5	9.9
1–3 months	0	0	3.2	0	0	0	1.3
3–6 months	0	0	0	0	1.9	0	2.0
Daily	0	5.6	1.6	5.5	5.7	9.7	6.6
Visit to a doctor or physiotherapist[b]	0	22.7	24.6	14.3	28.3	41.9	37.4
Medication and/or physical therapy	26.7	24.6	35.4	28.6	26.6	30.7	24.6
Sick leave (days)							
1–6	0	3.6	0	3.9	4.4	1.6	1.2
7–30	3.3	11.8	13.8	9.1	12.4	6.5	12.9
>30	0	0.9	1.5	1.3	0.9	3.2	1.2

χ^2-test: [a]$p<0.05$; [b]$p<0.01$.

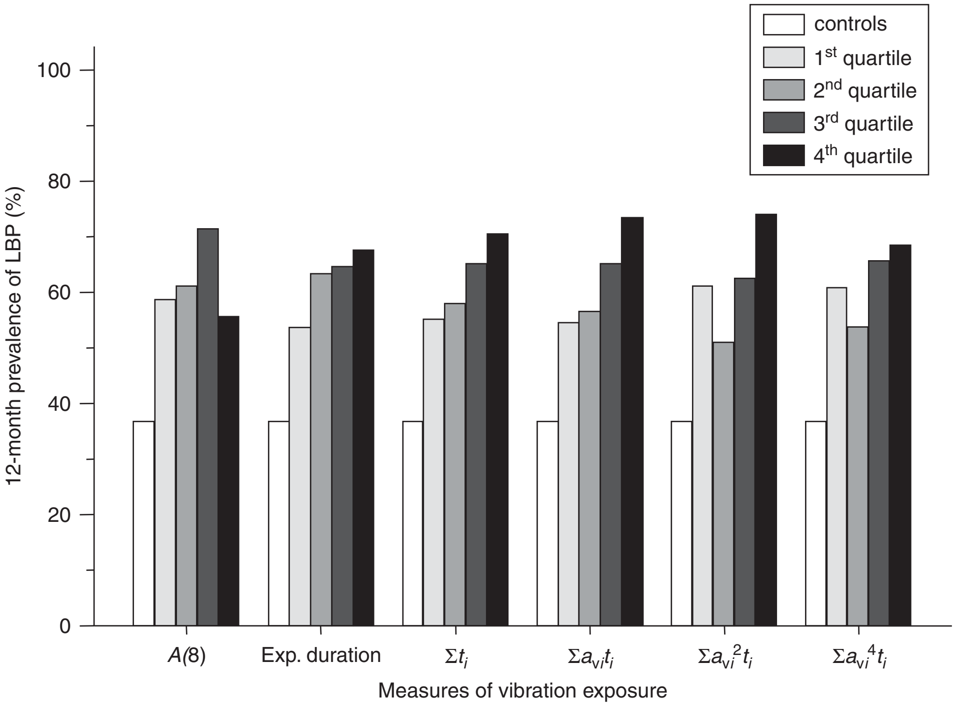

Fig. 1. Prevalence of low back pain (LBP) during the previous 12 months in the controls and the professional drivers by quartiles of alternative measures of whole-body vibration (WBV) exposure. WBV exposure was expressed in terms of 8-h energy-equivalent frequency-weighted acceleration magnitude ($A_v(8)$ in $\mathrm{m\,s^{-2}}$ rms), duration of exposure (years), and lifetime vibration doses estimated as the total driving time (t_i in h) alone or in combination with the vibration total value of the frequency-weighted accelerations (a_{vi} in $\mathrm{m\,s^{-2}}$ rms) measured on the machines used by the drivers.

However, when the several physical load variables were averaged within each subject to obtain a combined physical load index (see methods), the adjusted ORs showed a clear pattern of increasing risk for 12-month LBP and LBP disability with the increase of physical load grade from mild to very hard.

No significant interaction between postural load index and vibration exposure was observed when a two-product term for these variables was added to logistic regression models.

4. Discussion

The frequency-weighted acceleration magnitudes of vibration measured on the machines and vehicles investigated in this survey are very similar to those published in other reports, books and Internet resources [2,3,21–27]. Overall, the vibration total value, a_v, measured on the vehicles of the various companies ranged 0.2–1.3 (mean 0.56) $\mathrm{m\,s^{-2}}$ rms and the most severe axis acceleration ($1.4a_{wx}$, $1.4a_{wy}$, or a_{wz}) ranged 0.2–1.1 (mean 0.44) $\mathrm{m\,s^{-2}}$ rms. Paired data comparison showed that the difference between a_v and the most severe axis acceleration was highly significant ($p<0.001$). This finding has important repercussions on the estimation of daily vibration exposure, $A(8)$. In this study, we have estimated $A(8)$ using either a_v ($A_v(8)$) or the highest rms value of the dominant axis of vibration ($A_{\mathrm{dom}}(8)$) as the measure of frequency-weighted acceleration magnitude to be included in Eq. (2). In each driver group of this study, $A_v(8)$ was significantly greater than $A_{\mathrm{dom}}(8)$, (Table 4, $p<0.001$). The EU Directive on mechanical vibration has established a daily exposure action value $A_{\mathrm{dom}}(8)$ of $0.5\,\mathrm{m\,s^{-2}}$ rms above which the employer must implement a programme of technical and/or organisational measures intended to reduce to a minimum exposure to mechanical vibration and the associated risks [13]. Moreover, workers exposed to WBV in excess of the action value are entitled to appropriate health surveillance. In this study, 173 drivers (28.9%) were exposed to $A_v(8)$ greater than the daily exposure action value of $0.5\,\mathrm{m\,s^{-2}}$ rms, while this figure reduces to 89 drivers (14.9%) when daily vibration

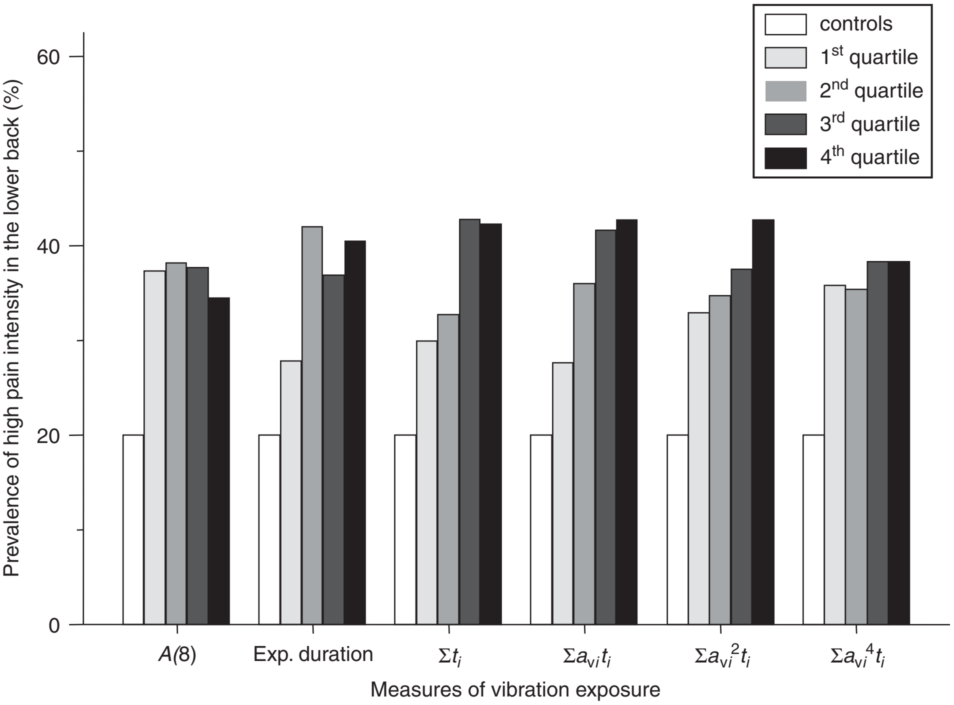

Fig. 2. Prevalence of high pain intensity in the lower back (Von Korff pain scale score $\geqslant 5$) during the previous 12 months in the controls and the professional drivers by quartiles of alternative measures of whole-body vibration (WBV) exposure. WBV exposure was expressed in terms of 8-h energy-equivalent frequency-weighted acceleration magnitude ($A_v(8)$ in $\mathrm{m\,s^{-2}}$ rms), duration of exposure (years), and lifetime vibration doses estimated as the total driving time (t_i in h) alone or in combination with the vibration total value of the frequency-weighted accelerations (a_{vi} in $\mathrm{m\,s^{-2}}$ rms) measured on the machines used by the drivers.

exposure was estimated as $A_{\mathrm{dom}}(8)$. As a result, if $A_{\mathrm{dom}}(8)$ is adopted as the basic indicator for the assessment of daily vibration exposure, in our study about 14% of the drivers would be excluded from health surveillance in case this latter is considered compulsory only for workers exposed to $A_{\mathrm{dom}}(8)$ above the action value. This is a matter of concern for the occupational health physician because in this study the occurrence of LBP outcomes in the overall driver group with $A_v(8) > 0.5\,\mathrm{m\,s^{-2}}$ rms was greater than that reported by the nested driver group with $A_{\mathrm{dom}}(8) > 0.5\,\mathrm{m\,s^{-2}}$ rms: 58.4 vs. 49.4% for 12-month LBP, 36.4 vs. 27.0% for high pain intensity, and 19.7% vs. 10.1% for LBP disability as defined in this study.

An important limitation of this study is the small size of the control group which may result in uncertainties of the risk estimates when the occurrence of LBP in the unexposed subjects is compared with that observed in the driver groups. The 12-month prevalence of LBP in our controls, however, was within the range of prevalence data for LBP in control groups (16–39%) reported by Dutch researchers in a series of epidemiological studies of LBP in professional drivers [2]. These findings are also similar to the weighted pooled prevalence of LBP among unexposed persons (30% in the age category 35–44 years) estimated in a recent meta-analysis of 40 studies which investigated work-relatedness of LBP in subjects exposed to several risk factors such as manual material handling, frequent bending and twisting of the trunk, WBV, heavy physical workload, and job satisfaction [28]. In the same meta-analysis, driving occupations with high exposure to WBV were significantly associated with the occurrence of 12-month LBP, and the overall pooled risk estimate (OR 2.63; 95% CI 1.69–4.10) was broadly comparable with that reported in our study (OR 2.81; 95% CI 1.31–6.04).

Our findings on LBP prevalence in the various driver groups seem to be consistent with those reported in other investigations. In a German study of professional drivers, the prevalence of "lumbar syndrome" (defined as "any kind of symptoms in the lumbar region and in the sacral area for which a vertebral cause could be assumed after differential diagnosis") was around 60% in operators of earth moving machines, truck drivers,

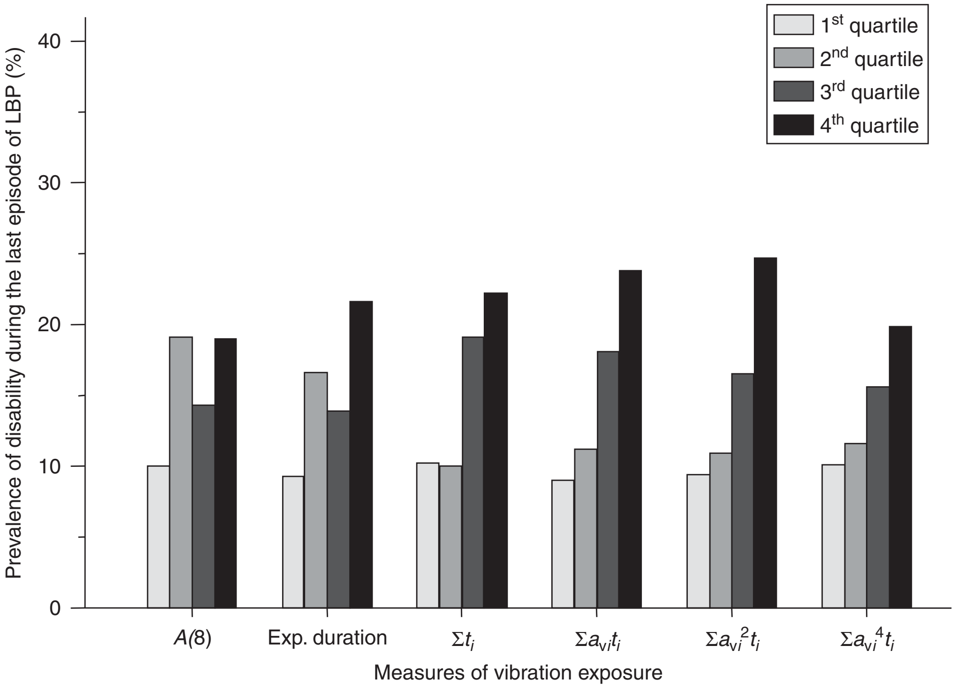

Fig. 3. Prevalence of disability (Roland & Morris disability scale score ⩾12) during the last episode of low back pain (LBP) in the professional drivers by quartiles of alternative measures of whole-body vibration (WBV) exposure. None of the controls reported disability due to LBP. WBV exposure was expressed in terms of 8-h energy-equivalent frequency-weighted acceleration magnitude ($A_v(8)$ in $\mathrm{m\,s^{-2}}$ rms), duration of exposure (years), and lifetime vibration doses estimated as the total driving time (t_i in h) alone or in combination with the vibration total value of the frequency-weighted accelerations (a_{vi} in $\mathrm{m\,s^{-2}}$ rms) measured on the machines used by the drivers.

and fork-lift truck drivers [23]. In a study of 169 fork-lift truck drivers from 13 companies in Copenhagen metropolitan area, the point prevalence (i.e. on the day of health examination) and the 12-month prevalence of LBP were 21% and 65%, respectively [29]. Moreover, there was an association between the occurrence of LBP and the length of employment (driving years) during the year preceding the survey. In Finland, Riihimäki et al. [30] found very high prevalence of 7-day and 12-month low back troubles (51% and 82%, respectively) in machine operators (541 longshoremen and 311 earthmover operators), but no significant relation between duration of employment and occurrence of low back symptoms. In our previous study of port machinery operators exposed to WBV and postural load, the overall 12-month prevalence of LBP was 63% [31]. Among the machine operators, LBP prevalence was greater in fork-lift truck drivers (79.5%) than in straddle carrier drivers (51.8%) and crane operators (54.4%). Bus drivers have been investigated in several epidemiological studies performed in US and European countries. A personal review of the available literature showed that the range of the prevalence of musculoskeletal disorders in the lower back of bus drivers was very wide between studies, from 40% to 82% [22]. In our epidemiological study of 234 urban bus drivers, low back symptoms occurred at WBV exposure levels ($0.4\,\mathrm{m\,s^{-2}}$ rms) that were lower than the health-based exposure limits proposed by the International Standard ISO 2631-1 [18].

In summary, the findings of the present investigation, as well as those of other epidemiological studies, tend to confirm the notion that driving occupations are associated with an increased risk for LBP. The variability of the risk estimates for LBP between studies of professional drivers may be due to differences in the study design, the characteristics of the study populations, the selection of control groups, the definition of LBP outcomes, and the assessment of exposure to WBV and other physical load factors. In spite of these limitations, there is a general agreement among experts that occupational exposure to WBV is one of the most important physical load risk factor for the occurrence of work-related low back disorders [7,8,11,28].

Table 9

Adjusted estimates of the odds ratio (OR) and 95% confidence interval (95% CI) for the association between low back pain (LBP) in the previous 12 months and alternative measures of exposure to whole-body vibration (WBV) in the total sample of professional drivers ($n = 598$). In the logistic regression models, each measure of WBV exposure was included as a quartile based design variable, assuming the lowest quartile as the reference category. The likelihood ratio (LR) test for the measures of WBV exposure and the Hosmer-Lemeshow (H–L) test for the goodness of fit of the logistic models are given

Measures of WBV exposure	Quartiles of measure of WBV exposure				LR test (χ^2, 3df[a])	H–L test (χ^2, 8df[a])
	1st	2nd	3rd	4th		
Duration (years)						
Median	2.0	7.0	17.0	24.0		
12-month LBP (%)	53.6	63.3	64.6	67.6	7.20	4.50
OR (95% CI)	1.0 (–)	1.67 (1.04–2.68)	1.62 (0.96–2.73)	2.15 (1.20–3.83)	($p = 0.066$)	($p = 0.81$)
$A_v(8)$ (m s^{-2} rms)						
Median	0.27	0.36	0.49	0.66		
12-month LBP (%)	58.7	61.1	71.4	55.6	3.83	11.8
OR (95% CI)	1.0 (–)	1.09 (0.66–1.79)	1.52 (0.89–2.60)	0.83 (0.51–1.35)	($p = 0.28$)	($p = 0.16$)
$\sum[t_i]$ (h × 10^3)						
Median	2.0	9.2	21.7	33.4		
12-month LBP (%)	55.1	58.0	65.1	70.5	8.98	6.35
OR (95% CI)	1.0 (–)	1.36 (0.84–2.20)	1.75 (1.05–2.91)	2.57 (1.45–4.54)	($p = 0.03$)	($p = 0.61$)
$\sum[a_{vi}t_i]$ (m s^{-2} h × 10^3)						
Median	1.0	4.5	11.6	18.2		
12-month LBP (%)	54.5	56.2	65.1	73.4	12.5	12.2
OR (95% CI)	1.0 (–)	1.25 (0.78–1.99)	1.77 (1.07–2.92)	2.81 (1.60–4.93)	($p = 0.006$)	($p = 0.15$)
$\sum[a_{vi}^2t_i]$ (m^2 s^{-4} h × 10^3)						
Median	0.56	1.9	6.4	10.9		
12-month LBP (%)	61.1	51.0	62.5	74.0	12.3	6.40
OR (95% CI)	1.0 (–)	0.69 (0.42–1.11)	1.11 (0.67–1.82)	1.84 (1.07–3.18)	($p = 0.006$)	($p = 0.60$)
$\sum[a_{vi}^4t_i]$ (m^4 s^{-8} h × 10^3)						
Median	0.11	0.41	2.3	4.8		
12-month LBP (%)	60.8	53.7	65.6	68.5	3.92	5.79
OR (95% CI)	1.0 (–)	0.75 (0.46–1.22)	1.07 (0.65–1.77)	1.27 (0.77–2.12)	($p = 0.43$)	($p = 0.67$)

a_v = vibration total value of weighted rms accelerations in the orthogonal axes x, y, z; t = total operating time; [a]df = degrees of freedom

Table 10
Adjusted estimates of the odds ratio (OR) and 95% confidence interval (95% CI) for the association between high pain intensity in the lower back (Von Korff pain scale score $\geqslant 5$) during the previous 12 months and alternative measures of exposure to whole-body vibration (WBV) in the total sample of professional drivers ($n = 598$). In the logistic regression models, each measure of WBV exposure was included as a quartile based design variable, assuming the lowest quartile as the reference category. The likelihood ratio (LR) test for the measures of WBV exposure and the Hosmer–Lemeshow (H–L) test for the goodness of fit of the logistic models are given

Measures of WBV exposure	Quartiles of measure of WBV exposure				LR test (χ^2, 3df[a])	H–L test (χ^2, 8df[a])
	1st	2nd	3rd	4th		
Duration (years)						
Median	2.0	7.0	17.0	24.0		
High pain intensity (%)	27.8	42.0	36.9	40.5	8.92	8.31
OR (95% CI)	1.0 (–)	1.97 (1.21–3.21)	1.61 (0.94–2.75)	2.13 (1.18–3.85)	($p = 0.03$)	($p = 0.40$)
$A_v(8)$ (m s^{-2} rms)						
Median	0.27	0.36	0.49	0.66		
High pain intensity (%)	37.3	38.2	37.1	34.5	0.60	5.30
OR (95% CI)	1.0 (–)	1.0 (0.62–1.64)	1.02 (0.64–1.62)	0.87 (0.54–1.42)	($p = 0.90$)	($p = 0.73$)
$\sum[t_i]$ (h × 10^3)						
Median	2.0	9.2	21.7	33.4		
High pain intensity (%)	29.9	32.7	42.8	42.3	9.57	6.97
OR (95% CI)	1.0 (–)	1.21 (0.73–2.00)	1.95 (1.17–3.23)	2.09 (1.19–3.68)	($p = 0.023$)	($p = 0.54$)
$\sum[a_{vi}t_i]$ (m s^{-2} h × 10^3)						
Median	1.0	4.5	11.6	18.2		
High pain intensity (%)	27.6	36.0	41.6	42.7	10.0	4.35
OR (95% CI)	1.0 (–)	1.51 (0.92–2.47)	2.04 (1.23–3.40)	2.24 (1.29–3.89)	($p = 0.018$)	($p = 0.82$)
$\sum[{a_{vi}}^2t_i]$ (m^2 s^{-4} h × 10^3)						
Median	0.56	1.9	6.4	10.9		
High LBP intensity (%)	32.9	34.7	37.5	42.7	3.51	3.56
OR (95% CI)	1.0 (–)	1.06 (0.65–1.73)	1.26 (0.77–2.06)	1.57 (0.94–2.62)	($p = 0.32$)	($p = 0.89$)
$\sum[{a_{vi}}^4t_i]$ (m^4 s^{-8} h × 10^3)						
Median	0.11	0.41	2.3	4.8		
High pain intensity (%)	35.6	35.5	37.4	39.3	0.57	4.45
OR (95% CI)	1.0 (–)	0.93 (0.57–1.50)	1.08 (0.67–1.74)	1.09 (0.67–1.79)	($p = 0.90$)	($p = 0.81$)

a_v = vibration total value of weighted rms accelerations in the orthogonal axes x, y, z; t = total operating time; [a]df = degrees of freedom.

Table 11

Adjusted estimates of the odds ratio (OR) and 95% confidence interval (95% CI) for the association between disability (Roland & Morris disability scale score $\geqslant 12$) during the last episode of low back pain (LBP) and alternative measures of exposure to whole-body vibration (WBV) in the total sample of professional drivers ($n = 598$). In the logistic regression models, each measure of WBV exposure was included as a quartile based design variable, assuming the lowest quartile as the reference category. The likelihood ratio (LR) test for the measures of WBV exposure and the Hosmer-Lemeshow (H–L) test for the goodness of fit of the logistic models are given

Measures of WBV exposure	Quartiles of measure of WBV exposure				LR test (χ^2, 3df[a])	H–L test (χ^2, 8df[a])
	1st	2nd	3rd	4th		
Duration (years)						
Median	2.0	7.0	17.0	24.0		
LBP disability (%)	9.3	16.6	13.9	21.6	4.51	10.8
OR (95% CI)	1.0 (–)	1.83 (0.90–3.71)	1.39 (0.64–3.02)	2.25 (1.00–5.08)	($p = 0.21$)	($p = 0.21$)
$A_v(8)$ (m s^{-2} rms)						
Median	0.27	0.36	0.49	0.66		
LBP disability (%)	10.0	19.1	14.3	19.0	6.93	7.49
OR (95% CI)	1.0 (–)	2.19 (1.08–4.44)	1.63 (0.80–3.30)	2.19 (1.09–4.42)	($p = 0.074$)	($p = 0.48$)
$\sum[t_i]$ (h × 10^3)						
Median	2.0	9.2	21.7	33.4		
LBP disability (%)	10.2	10.0	19.1	22.2	8.27	1.01
OR (95% CI)	1.0 (–)	1.01 (0.47–2.19)	2.14 (1.06–4.35)	2.46 (1.14–5.31)	($p = 0.041$)	($p = 0.99$)
$\sum[a_{vi}t_i]$ (m s^{-2}h × 10^3)						
Median	1.0	4.5	11.6	18.2		
LBP disability (%)	9.0	11.2	18.1	23.8	9.99	4.12
OR (95% CI)	1.0 (–)	1.19 (0.55–2.56)	2.40 (1.15–5.03)	2.97 (1.37–6.63)	($p = 0.019$)	($p = 0.85$)
$\sum[a_{vi}{}^2t_i]$ (m^2 s^{-4} h × 10^3)						
Median	0.56	1.9	6.4	10.9		
LBP disability (%)	9.4	10.9	16.5	24.7	10.3	6.54
OR (95% CI)	1.0 (–)	1.05 (0.49–2.28)	1.88 (0.91–3.91)	2.77 (1.34–5.72)	($p = 0.016$)	($p = 0.59$)
$\sum[a_{vi}{}^4t_i]$ (m^4 s^{-8} h × 10^3)						
Median	0.11	0.41	2.3	4.8		6.62
LBP disability (%)	9.4	15.1	17.0	20.0	9.00	($p = 0.58$)
OR (95% CI)	1.0 (–)	1.16 (0.55–2.47)	1.66 (0.81–3.37)	2.50 (1.26–4.99)	($p = 0.029$)	

a_v = vibration total value of weighted rms accelerations in the orthogonal axes x, y, z ; t = total operating time; [a]df = degrees of freedom.

Table 12
Adjusted estimates of the odds ratio (OR) and 95% confidence interval (95% CI) for low back pain (LBP) in the previous 12 months and disability (Roland & Morris disability scale score $\geqslant 12$) during the last episode of LBP in the professional drivers according to work-related physical load variables

Variable	12-month LBP OR (95% CI)	LBP disability OR (95% CI)
Walking & standing at work		
Never	1.0 (–)	1.0 (–)
<1 h/d	0.71 (0.37–1.37)	1.08 (0.47–2.48)
1–3 h/d	1.09 (0.58–2.05)	1.01 (0.45–2.23)
>3 h/d	0.91 (0.45–1.84)	1.12 (0.45–2.79)
Trunk bent 20–40°		
Never	1.0 (–)	1.0 (–)
<1 h/d	2.16 (1.14–4.08)	2.66 (1.38–5.14)
1–2 h/d	2.17 (1.05–4.47)	2.66 (1.25–5.67)
>2 h/d	1.04 (0.38–2.86)	0.94 (0.20–4.39)
Trunk bent >40°		
Never	1.0 (–)	1.0 (–)
<1 h/d	2.53 (1.30–4.92)	2.13 (1.07–4.25)
1–2 h/d	1.97 (0.95–4.10)	2.64 (1.21–5.77)
>2 h/d	0.99 (0.35–2.80)	1.15 (0.24–5.46)
Trunk twisted & bent 20–40°		
Never	1.0 (–)	1.0 (–)
<1 h/d	1.34 (0.70–2.58)	1.78 (0.86–3.68)
1–2 h/d	2.92 (1.06–8.05)	2,28 (0.88–5.92)
>2 h/d	1.18 (0.39–3.63)	1.29 (0.34–4.88)
Trunk twisted & bent >40°		
Never	1.0 (–)	1.0 (–)
<0.5 h/d	1.58 (0.80–3.12)	1.81 (0.87–3.75)
0.5–2 h/d	3.28 (1.08–9.96)	2.51 (0.95–6.59)
>2 h/d	1.42 (0.42–4.80)	1.70 (0.44–6.63)
Arms raised & hands above shoulders		
Never	1.0 (–)	1.0 (–)
<1 h/d	1.80 (1.13–2.87)	1.06 (0.62–1.82)
1–3 h/d	1.68 (0.52–5.46)	0.34 (0.04–2.68)
>3 h/d	1.65 (0.14–18.7)	3.21 (0.27–38.3)
Lifting loads >15 kg		
Never	1.0 (–)	1.0 (–)
1–15 min/d	1.23 (0.80–1.89)	1.87 (1.13–3.11)
15–45 min/d	0.64 (0.30–1.40)	1.11 (0.36–3.41)
>45 min/d	3.98 (0.47–33.8)	3.94 (0.71–21.9)
Back bent forward or twisted while driving		
Never	1.0 (–)	1.0 (–)
Seldom	1.61 (0.98–2.63)	0.90 (0.43–1.89)
Often	2.25 (1.42–3.57)	1.55 (0.80–3.00)
Physical load index (grade)		
Mild	1.0 (–)	1.0 (–)
Moderate	1.71 (1.02–2.86)	1.32 (0.60–2.92)
Hard	1.80 (1.08–2.99)	2.36 (1.10–5.04)
Very hard	2.25 (1.39–3.64)	2.57 (1.25–5.26)

According to annex B to International Standard ISO 2631-1 (“Guide to the effects of vibration on health”), “increased duration (within the working day or daily over years) and increased vibration intensity mean increased vibration dose and are assumed to increase the risk, while periods of rest can reduce the risk. There are not sufficient data to show a quantitative relationship between vibration exposure and risk of health effects. Hence, it is not possible to assess whole-body vibration in terms of the probability of risk at various exposure magnitudes and durations" [18]. The ISO statement is based on the results of some scientific reviews which concluded for the existence of a strong association between WBV exposure and disorders of the lumbar spine, but also pointed out that the cross-sectional design of most of the published epidemiological studies, as well as the heterogeneity of the reported risk estimates for LBP disorders, hampered to draw a clear relationship between occupational exposure to WBV and the occurrence of adverse health effects on the lower back [2,4,6]. Some authors have argued that, although dose–response trend was seen in several epidemiological studies, the observed effect might be due to exposure to either WBV or other physical load factors since driving occupations involve prolonged sitting in a constrained posture, non-neutral movements while driving, and sometimes weight lifting and carrying [2,7,11]. Therefore, it may be difficult to differentiate the relative role of WBV and other physical load factors in the aetiology of low back disorders and pathological changes in the spinal system of drivers [7].

We recognise that the major limitation of the present study is its cross-sectional design that may result in health-based selection and difficulty in assessing the temporal relationship between exposure to physical workplace factors and LBP outcomes. Nevertheless, we attempted to explore some preliminary elements of dose–response relationship by pooling exposure and health data from the whole driver population. Moreover, we examined tentatively the accuracy of the prediction of the outcomes using alternative measures of vibration exposure as explanatory variables while adjusting for other risk factors known to be potentially associated with the occurrence of low back disorders.

In this study, multivariate data analysis showed that the currently recommended measure of daily vibration exposure ($A(8)$) was not associated with any LBP outcome. Duration of exposure in terms of total driving hours ($\sum[t_i]$) was a better predictor of LBP than full-time driving years. Of the three measures of vibration dose computed from weighted acceleration magnitude (a_i) and total driving hours (t_i), dose measure which gives equal weight to a_i and t_i, i.e. $\sum[a_{vi}t_i]$, was the only one that showed significant associations with all LBP outcomes investigated in this study. Lifetime exposure duration (total driving hours, $\sum[t_i]$) gave better predictions than measures with power of acceleration greater than unity. Even though both dose $\sum[t_i]$ and dose $\sum[a_{vi}t_i]$ were significantly related to the occurrence of LBP, high pain severity and disability in the lower back, the significance of the LR statistic and the pattern of increasing ORs with the increase of cumulative vibration exposure seem to suggest that after controlling for potential confounders, dose $\sum[a_{vi}t_i]$ performed better than dose determined solely by lifetime exposure duration (without consideration of the vibration magnitude).

The lack of association between daily vibration exposure ($A(8)$) and LBP in the drivers of this study may depend on the chronic nature of low back symptoms or disorders whose appearance and development require a gradual accumulation of vibration-induced injuries over time. This may explain our findings that measures of vibration dose which include lifetime exposure duration were better predictors of LBP than a dose measure, such as $A(8)$, that takes into account only current daily exposure time. Laboratory studies have provided biological plausibility for the chronic effects of vibration on the anatomical structures of the spine. Vibration can provoke spinal pathology through mechanical damage and interference with tissue nutrition which lead to degeneration and microfracturing of the vertebral end-plates, increase of intradiscal pressure, and rupture of disc fibres [32,33]. Moreover, electromyographic studies have shown than vibration exposure can induce fatigue and exhaustion of the paravertebral muscles of the lower back resulting in increased instability of the lumbar tract of the spine [32].

In this study, non-neutral trunk postures while driving were significant predictors of LBP prevalence. A physical load index, derived from combining manual materials handling and awkward postures, was significantly related (on a log-scale) to LBP outcomes. After adjusting for vibration exposure and other individual and work-related risk factors, the excess risk of LBP was significantly increased for hard and very hard physical load grade when compared with mild grade. These findings are consistent with those of several epidemiological studies, reviews and meta-analyses which concluded that there is a strong evidence for a positive relationship between (low) back disorders and lifting loads, frequent trunk bending and twisting, and WBV exposure at workplace [7,8,11,28,30,32]. This view is also supported by the findings of experimental investigations which showed that non-neutral trunk postures can combine with seated WBV exposure to increase the risk of degenerative changes in the spine [1,3,9,32]. On the contrary, in this study prolonged sitting in an unconstrained posture was not associated with LBP and this is consistent with the finding that sitting-while-working is poorly correlated with low back symptoms [34].

The procedures we used to assess vibration exposure and other physical load risk factors in the professional drivers are subject to several sources of uncertainty. Vibration magnitude of vehicles was measured by a root-mean-square averaging procedure, i.e. rms acceleration. It is possible that different averaging methods might change the fitting performance of the dose models estimated in this study. The ISO standard 2631-1 [18] suggests that health disorders may be underestimated by rms averaging if vibration exposure involves impulsiveness. In case of exposure to vibration with crest factor above 9, the fourth power averaging method (root-mean-quad) is considered more appropriate to assess possible adverse health effects. Hence, the interpretation of the findings of the present study should be limited to exposure conditions evaluated in terms of rms acceleration magnitude.

In our study, daily and lifetime exposure durations were determined by interviewing employees and employers. As a result, recall bias cannot be ruled out. However, a recent national survey in Great Britain [35] has shown a good agreement between reported and observed duration of exposure to WBV in a sample of drivers of industrial and agricultural machines (median ratio of reported to observed time: 1.1). In our study, personal time schedules were available for drivers employed in public utilities, and this allowed a more objective estimation of daily exposure duration for these job categories. Vibration doses were estimated on the basis of exposure duration (total hours) in current jobs and this may have lead to underestimation of cumulative vibration exposure in drivers with previous jobs with WBV exposure. To adjust, at least partially, for this exposure bias, years of previous employment as a driver were included as an independent variable in multivariate logistic data analysis. Dose models showed that total exposure duration (in hours) was a better predictor of LBP outcomes than exposure duration in full-time driving years, suggesting that lifetime exposure in hours discriminates between short and prolonged daily exposure time. A further uncertainty in the estimation of lifetime vibration exposure may arise because vibration measurements were made on currently available machines or vehicles, even though a limited number of vibration measurements were also performed on old machinery, mainly in dockyards. Nevertheless, the weighted rms acceleration magnitude of vibration measured in the vehicles of the present study are highly comparable with those reported in recent and past investigations [1–3,21,24,26,27].

In this study, work-related physical loading other than mechanical vibration was evaluated by a mixed approach based on both direct observation of working conditions and subjective judgement of the frequency and duration of awkward postures and heavy manual work. Since the association between LBP outcomes and physical load risk factors was evaluated mainly on the basis of self-reported working postures and manual material handling, potential bias for spurious associations between exposures and symptoms cannot be ruled out. Previous studies, however, found that individuals with musculoskeletal disorders did not tend to overestimate their physical work load when questionnaire data were compared with systematic observations [36]. Moreover, ergonomic investigations have shown a good agreement between self-reported and observed frequency, duration, and magnitude of physical demands [37]. Although the role of the questionnaire as an instrument for assessing occupational physical stressors is still controversial [38–40], questionnaire methods may offer benefits for studying cumulative exposure over time, a variable which cannot be estimated by direct observations or measurements [41].

Another source of error may derive from the cross-sectional design of the present study. The overall occurrence of LBP outcomes may be biased owing to the "healthy worker effect", i.e. individuals may have left the cohort because of the development of severe low back symptoms, and this may give rise to underestimation of the risk associated with exposure to occupational risk factors. Unfortunately, the magnitude of this selection bias cannot be estimated in this study, even though information from employers suggests that the workforce turnover in the last decade was very low, at least for drivers employed in marble quarries and laboratories.

This study showed no clear relationship between LBP outcomes and work-related psychosocial factors. After adjustment for age, only the occurrence of 7-day and 12-month LBP was marginally associated with job decision and job support. Multivariate data analysis did not show substantial changes in the associations. More severe LBP outcomes, such as high pain intensity and disability, were not related to psychosocial variables. The link between (low) back symptoms and psychosocial factors at work is still a controversial matter. In a series of reviews and meta-analyses conducted by Dutch investigators, it was concluded for a positive evidence of low workplace social support, low job satisfaction, and low job decision latitude as risk factors for musculoskeletal disorders (back pain included), even though the magnitude of this evidence varied across different studies and study designs [10,11,28,42]. On the contrary, a recent systematic review of 40 prospective cohort studies found moderate evidence for no positive association between perception of work, organisational aspects of work, and social support at work and LBP, as well as insufficient evidence for a positive association between stress at work and LBP [43]. Similar findings, even in a more negative direction, were reported for the association between workplace psychosocial factors and consequences of LBP (sick leave, delayed return to work, disability pension, etc.). The authors pointed out the heterogeneity of the reviewed studies, mainly with reference to the different definitions of LBP and psychosocial factors used in the various investigations, the variety of instruments to collect exposure and outcome data, and the lack of standardisation for the metric utilised to quantify psychosocial variables. By the light of these major methodological problems, and considering that the possible aetiological mechanisms are poorly understood, the reviewers concluded that randomness for the associations reported in some studies cannot be excluded.

Even though the present study is affected with the aforementioned shortcomings due to its cross-sectional design, nevertheless our findings of a weak association between work-related psychosocial factors and LBP outcomes seems to reflect the contradictory picture emerging from the review of the scientific literature on the subject.

5. Conclusion

This cross-sectional study tends to confirm that professional driving in industry and public utilities is associated with an increased risk of work-related LBP. Occupational exposure to WBV and physical loading factors at work are important components of the multifactorial origin of LBP in professional drivers. In multivariate data analysis, individual characteristics (e.g. age, body mass index) were also significantly associated with LBP outcomes, while psychosocial work factors (e.g. job decision, job support) showed a marginal relation to LBP.

The ongoing longitudinal study of the driver groups within the VIBRISKS project will seek to improve knowledge of the exposure–response relationship between whole-body vibration and the occurrence of low back disorders, and to advance understanding of the other physical and psychosocial factors that combine to result in the progression of low back symptoms.

Acknowledgement

This research was supported by the European Commission under the Quality of Life and Management of Living Resources programme—Project No. QLK4-2002-02650 (VIBRISKS), and by the Istituto Superiore per la Prevenzione e la Sicurezza del Lavoro (ISPESL, Rome)—Contract CM3/DIL/03.

References

[1] H. Dupuis, G. Zerlett, *The Effects of Whole-Body Vibration*, Springer, Berlin, 1986.
[2] P.M. Bongers, H.C. Boshuizen, Back disorders and whole-body vibration at work, Academisch Proefschrift, Universiteit van Amsterdam, 1990.
[3] M.J. Griffin, *Handbook of Human Vibration*, Academic Press, London, 1990.
[4] H. Seidel, Selected health risks caused by long-term whole-body vibration, *American Journal of Industrial Medicine* 23 (1993) 589–604.
[5] Comité Européen de Normalisation, Mechanical vibration—guide to the health effects of vibration on the human body. CR Report 12349, Brussels, 1996.
[6] C.T.J. Hulshof, O.B.A. Veldhuijzen van Zanten, Whole-body vibration and low back pain—a review of epidemiologic studies, *International Archives of Occupational and Environmental Health* 59 (1987) 205–220.
[7] M. Bovenzi, C.T.J. 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.

[8] National Institute for Occupational Safety and Health, Musculoskeletal disorders and workplace factors—a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. DHHS (NIOSH) Publication No. 97-141, Cincinnati, OH, 1997.

[9] D.G. Wilder, The biomechanics of vibration and low back pain, *American Journal of Industrial Medicine* 23 (1993) 577–588.

[10] P.M. Bongers, C.R. de Winter, M.A.J. Kompier, V.H. Hildebrandt, Psychosocial factors at work and musculoskeletal disease, *Scandinavian Journal of Work, Environment & Health* 19 (1993) 297–312.

[11] A. Burdorf, G. Sorock, Positive and negative evidence on risk factors for back disorders, *Scandinavian Journal of Work, Environment & Health* 23 (1997) 243–256.

[12] http://www.humanvibration.com.

[13] The European Parliament and the Council of the European Union, On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). Directive 2002/44/EC. *Official Journal of the European Communities*, 6th July 2002, L 117/13–19.

[14] M. Pope, M. Magnusson, R. Lundström, C. Hulshof, J. Verbeek, M. Bovenzi, Guidelines for whole-body vibration health surveillance, *Journal of Sound and Vibration* 253 (2002) 131–167.

[15] I. Kuorinka, B. Jonsson, Å. Kilbom, H. Vinterberg, F. Biering-Sørensen, G. Andersson, K. Jørgensen, Standardised Nordic questionnaire for the analysis of musculo-skeletal symptoms, *Applied Ergonomics* 18 (1987) 233–237.

[16] M. Von Korff, J. Ormel, F.J. Keefe, S.F. Dworkin, Grading the severity of pain, *Pain* 50 (1992) 133–149.

[17] M. Roland, R. Morris, A study of the natural history of back pain, part 1: development of a reliable and sensitive measure of disability on low-back pain, *Spine* 8 (1983) 141–144.

[18] International Organization for Standardization ISO 2631-1, Mechanical vibration and shock—guide for the evaluation of human exposure to whole- body vibration—part 1: general requirements, 1997.

[19] D.W. Hosmer, S. Lemeshow, *Applied Logistic Regression*, second ed., Wiley, New York, 2000.

[20] Cytel Statistical Software, *LogXact Version 6.0—Discrete Regression Software Featuring Exact Methods*, Cytel Software Corporation, Cambridge, MA, 2004.

[21] International Social Security Association (ISSA), *Vibration at Work*, International Section Research, Institut National de Recherche et de Sécurité (INRS), Paris, 1989.

[22] M. Bovenzi, A. Zadini, Self-reported low back symptoms in urban bus drivers exposed to whole-body vibration, *Spine* 17 (1992) 1048–1059.

[23] S. Schwarze, G. Notbohm, H. Dupuis, E. Hartung, Dose–response relationships between whole-body vibration and lumbar disk disease—a field study on 388 drivers of different vehicles, *Journal of Sound and Vibration* 215 (1998) 613–628.

[24] G.S. Paddan, B.M. Haward, M.J. Griffin, K.T. Palmer, *Whole-Body Vibration: Evaluation of Some Common Sources of Exposure in Great Britain*, Health and Safety Executive, The Stationery Office, London, 1999.

[25] 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, *Occupational and Environmental Medicine* 57 (2000) 229–236.

[26] http://umetech.niwl.se.

[27] http://www.ispesl.it.

[28] F. Lötters, A. Burdorf, J. Kuiper, H. Miedema, Model for the work-relatedness of low back pain, *Scandinavian Journal of Work, Environment & Health* 29 (2003) 431–440.

[29] T. Brendstrup, F. Biering-Sørensen, Effect of fork-lift truck driving on low-back trouble, *Scandinavian Journal of Work, Environment & Health* 13 (1987) 442–452.

[30] H. Riihimäki, S. Tola, T. Videman, K. Hänninen, Low-back pain and occupation—a cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work, *Spine* 14 (1989) 204–209.

[31] M. Bovenzi, I. Pinto, N. Stacchini, Low back pain in port machinery operators, *Journal of Sound and Vibration* 253 (2002) 3–20.

[32] B.O. Wikström, A. Kjellberg, U. Landström, Health effects of long-term occupational exposure to whole-body vibration: a review, *International Journal of Industrial Ergonomics* 14 (1994) 273–292.

[33] D.G. Wilder, M.H. Pope, Epidemiological and aetiological aspects of low back pain in vibration environment—an update, *Clinical Biomechanics* 11 (1996) 61–73.

[34] J. Hartvigsen, C. Leboeuf-Yde, S. Lings, E.H. Corder, Is sitting-while-at-work associated with low back pain? A systematic, critical literature review, *Scandinavian Journal of Public Health* 28 (2000) 230–239.

[35] 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, *Occupational and Environmental Medicine* 57 (2000) 237–241.

[36] E.B. Holmström, J. Lindell, U. Moritz, Low back and neck/shoulder pain in construction workers: occupational workload and psychosocial risk factors—part 1: relationship to low back pain, *Spine* 17 (1992) 663–671.

[37] D.P. Pope, A.J. Silman, N.M. Cherry, C. Pritchard, G.J. Macfarlane, Validity of a self-completed questionnaire measuring the physical demands of work, *Scandinavian Journal of Work, Environment & Health* 24 (1998) 376–385.

[38] A. Burdorf, A.J. van der Beek, In musculoskeletal epidemiology are we asking the unanswerable in questionnaires on physical load?, *Scandinavian Journal of Work, Environment & Health* 25 (1999) 81–83.

[39] S. Hollmann, F. Klimmer, K.-H. Schmidt, H. Kylian, Validation of a questionnaire for assessing physical work load, *Scandinavian Journal of Work, Environment & Health* 25 (1999) 105–114.

[40] G.-Å. Hansson, I. Balogh, J.U. Byström, K. Ohlsson, C. Nordander, P. Asterland, S. Sjölander, L. Rylander, J. Winkel, S. Skerfving, Malmö Shoulder-Neck Study Group, Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands, *Scandinavian Journal of Work, Environment & Health* 27 (2001) 30–40.

[41] Å. Kilbom, Assessment of physical exposure in relation to work-related musculoskeletal disorders—what information can be obtained from systematic observations?, *Scandinavian Journal of Work, Environment & Health* 20 (1994) 30–45.

[42] W.E. Hoogendoorn, M.N.M. van Poppel, P.M. Bongers, B.W. Koes, L.M. Bouter, Systematic review of psychosocial factors at work and private life as risk factors for back pain, *Spine* 25 (2000) 2114–2125.

[43] J. Hartvigsen, S. Lings, C. Leboeuf-Yde, L. Bakketeig, Psychosocial factors at work in relation to low back pain and consequences of low back pain: a systematic, critical review of prospective cohort studies, *Occupational and Environmental Medicine* 61 (2004) 1–10 electronic review, e2 http://www.occenvmed.com/cgi/content/full/61/1/e2.