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LOW BACK PAIN IN PORT MACHINERY OPERATORS

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The occurrence of several types of low back pain (LBP) was investigated by a standardized questionnaire in a group of 219 port machinery operators exposed to whole-body vibration (WBV) and postural load and in a control group of 85 maintenance workers employed at the same transport company. The group of port machinery operators included 85 straddle carrier drivers, 88 fork-lift truck drivers, and 46 crane operators. The vector sum of the frequency-weighted r.m.s. acceleration of vibration measured on the seatpan of port vehicles and machines averaged 0·90 m/s^2 for fork-lift trucks, 0·48 m/s^2 for straddle carriers, 0·53 m/s^2 for mobile cranes, and 0·22 m/s^2 for overhead cranes. The 12-month prevalence of low back symptoms (LBP, sciatic pain, treated LBP, sick leave due to LBP) was significantly greater in the fork-lift truck drivers than in the controls and the other two groups of port machinery operators. After adjusting for potential confounders, the prevalence of low back symptoms was found to increase with the increase of WBV exposure expressed as duration of exposure (driving years), equivalent vibration magnitude (m/s^2), or cumulative vibration exposure (yr m^2/s^4). An excess risk for lumbar disc herniation was observed in the port machinery operators with prolonged driving experience. In both the controls and the port machinery operators, low back complaints were strongly associated with perceived postural load assessed in terms of frequency and/or duration of awkward postures at work. Multivariate analysis showed that vibration exposure and postural load were independent predictors of LBP. Even though the cross-sectional design of the present study does not permit firm conclusions on the relationship between WBV exposure and low back disorders, the findings of this investigation provide additional epidemiological evidence that seated WBV exposure combined with non-neutral trunk postures, as while driving, is associated with an increased risk of long-term adverse health effects on the lower back.

1. INTRODUCTION

Long-term occupational exposure to whole-body vibration (WBV) is associated with an increased risk of disorders of the lumbar spine and the connected nervous system [1–6]. It has been estimated that 4–7% of all employees in the U.S., Canada, and some European countries are exposed to potentially harmful WBV [4, 5]. A recent review of epidemiological studies conducted between 1986 and 1997 has provided substantial evidence for an increased occurrence of low back pain, sciatic pain, and degenerative changes in the spinal system, including lumbar intervertebral disc disorders, among drivers of vehicles and

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machines used in industry, farming and forestry work, and in road transport [5]. In some countries, back disorders occurring in workers exposed to WBV are considered to be an occupational disease which is compensable [4].

The role of WBV in the aetiopathogenesis of low back injuries 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 static posture, bending forward and frequent twisting of the spine. 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 (age, anthropometric data, smoking habit, constitutional susceptibility), psychosocial factors, and previous back traumas are also recognized as potential predictors for low back pain [4, 5, 7–9]. It follows that injuries in the lower back of professional drivers may be considered a complex of health disorders of multifactorial origin involving both occupational and non-occupational stressors.

Although there is evidence for a complicated relation between individual and work-related factors in the aetiopathogenesis of low back pain, epidemiological studies may contribute to understanding the relative role of WBV and other risk factors in the onset and the development of low back disorders and pathological changes in the spinal system of professional drivers. The aim of this study was to investigate the occurrence of several types of low back symptoms in the machine operators of a transport company in the Port of Trieste (Italy). The control group consisted of workers employed at the same company and not exposed to WBV. Vibration measurements were performed on a representative sample of the vehicles and machines used by the port machinery operators. Finally, the association between low back disorders, WBV exposure and perceived postural load was investigated while controlling for potential confounders recognized as risk factors for low back pain.

2. SUBJECTS AND METHODS

2.1. STUDY POPULATION

The source population for this study was represented by all male workers who were employed on January 1, 1997 at a transport company in the container port of Trieste, Northeastern Italy. The study population comprised 245 port machinery operators and 117 randomly selected manual workers involved in maintenance operations. The port machinery operators included drivers of straddle carriers, fork-lift trucks, and freight-container tractors, as well as operators of overhead and mobile cranes. The main task of the crane operators is to load and unload containers from the ship to the quay. The task of the drivers of straddle carriers (loading capacity 30·5 t) is the transport of freight containers from the quay to the stack. Fork-lift trucks (loading capacity 6–16 t) and large tractors are used to transport and stack parcel goods and freight containers respectively. The control group included maintenance workers such as mechanics, electricians and general operators who performed manual activities at the same company and were not exposed to WBV from vehicles or machines.

Since the subjects were interviewed in connection with the annual compulsory health examination, the rate of participation in the study was 100% for the port machinery operators. During the medical interview, they filled in a structured questionnaire containing questions about individual characteristics, work conditions and musculoskeletal symptoms. Workers aged 25–55 years and employed in the current job for at least 12 months were included in the study population. The following criteria were adopted to exclude subjects from data analysis: (a) low back complaints prior to the current work; (b) change in job title in the current company because of back disorders; (c) exposure to WBV, as a professional driver, in previous jobs. Freight-container tractor drivers were also excluded because of the small sample size ($n = 15$). Thus, the final sample consisted of 219 port machinery operators and 85 control manual workers. The group of port machinery operators included 85 straddle carrier drivers, 88 fork-lift truck drivers, and 46 crane operators.

2.2. THE QUESTIONNAIRE

The questionnaire consisted of four major sections. The first section included items on the subject's personal characteristics such as age, height, weight, smoking and drinking habits, education, marital status, leisure activities, and annual amount of car driving. The second section requested information on occupational history in the current and previous companies with details about job titles, duration of employment, types of machines or vehicles driven, and aspects related to heavy physical work and postural load. The third section focused on low back complaints which were investigated using a modified version of the Nordic questionnaire on musculoskeletal symptoms [10]. The workers were questioned on several types of low back symptoms or disorders defined as follows: (i) low back pain (LBP): ache, pain, or stiffness in the lower part of the back during lifetime or in the previous 12 months; (ii) sciatica: radiating pain in one or both legs in the previous 12 months; (iii) disc herniation: herniation of lumbar intervertebral disc visualized by computed tomography or magnetic resonance imaging, with or without electroneuromyographic signs of nerve root compression. Evidence of disc herniation was obtained from medical records. Further questions concerned duration of LBP, health care use because of LBP, treatment for LBP (anti-inflammatory drugs or physical therapy), and sick leave due to LBP in the previous 12 months. Back traumas or accidents having required medical advice or treatment were carefully investigated. The fourth section of the questionnaire contained items on general aspects of the work environment in terms of physical hazards (climatic working conditions) and perceived mental stress during working. Questions on job satisfaction, level of job responsibility, and stressful work events were derived from validated questionnaires [11].

2.3. MEASUREMENT AND ASSESSMENT OF VIBRATION EXPOSURE

Vibration measurements were performed on a representative sample of the straddle carriers ($n = 7$), fork-lift trucks ($n = 7$), and cranes ($n = 4$) used by the port machinery operators. Vibration was measured on the seatpan of the machines under actual operating conditions according to the recommendations of the International Standard ISO 2631-1 [12, 13]. From one-third octave band frequency spectra (1–80 Hz) recorded from x, y, and z directions, frequency-weighted root-mean-square (r.m.s.) 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 r.m.s. accelerations, a_v, was calculated according to the following formula:

$$a_v = [(1{\cdot}4a_{wx})^2 + (1{\cdot}4a_{wy})^2 + a_{wz}^2]^{1/2} .$$

For each operator, 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. The company records were considered as reliable sources of information about WBV exposure because foremen and driver instructors have the responsibility to compile individual records in which the driving history of each operator is reported in terms of duration of driving per type of vehicle, per day and per calendar year.

Whole-body weighted acceleration sum and duration of exposure were used to construct two measures of vibration exposure, called "equivalent vibration magnitude" and "cumulative vibration exposure" [1, 14, 15]. The equivalent vibration magnitude was calculated as:

$$\textit{Equivalent vibration magnitude} = [\sum(a_{vi}^2 t_i)/t_i]^{1/2} \quad (\mathrm{m/s^2\ r.m.s.}),$$

where a_{vi} is the estimated vector sum of the frequency-weighted accelerations measured on machine i driven for time t_i in years.

Cumulative vibration exposure was calculated according to the energy equivalence principle using the "second power" time dependency proposed by ISO 2631-1 for daily exposures:

$$\textit{Cumulative vibration exposure} = \sum a_{vi}^2 t_i \ (\mathrm{yr\ m^2/s^4}).$$

Both equivalent vibration magnitude and cumulative vibration exposure were calculated for each port machinery operator.

2.4. ASSESSMENT OF POSTURAL 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 postural load in the manual workers and the port machinery operators.

An ergonomic checklist showed that possible risk factors for back disorders such as lifting and carrying were more frequent in the control group than in the WBV exposed group. As expected, maintenance tasks involved more dynamic physical work than driving operations. Static load due to prolonged sitting was predominant in the port machinery operators compared with the controls, while the frequency of non-neutral trunk postures was similar in the two groups.

In the questionnaire, awkward postures at work (prolonged sitting, lifting, bending forward and twisting) were assessed by rating the frequency and/or the duration of each posture on a four-item index scale assigning a value from 1 to 4 ("seldom", "sometimes", "often", "very often") [15, 16]. A mean value of the postural indices during a typical workday was calculated for each subject and a new measure of perceived postural load was constructed by categorizing the average postural load into four grades: mild = 1–1·49, moderate = 1·5–1·99, hard = 2–2·99, very hard = 3–4.

2.5. DATA ANALYSIS

The statistical analysis of data was performed with the software Stata, version 6·0 (Stata Corporation, 1999). Continuous variables were summarized 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 an unpaired Student's t-test or an analysis of variance and multiple comparisons respectively. The difference between categorical data cross-tabulated into contingency tables was tested by the chi-square statistic. The association between low back symptoms and several independent variables was assessed by fitting log-binomial regression models. Prevalence ratios (PR) and 95%

confidence intervals (95% *CI*) were estimated from the regression coefficients and standard errors. Initially, univariate associations were examined to study the effect of various predictors on the occurrence of low back complaints. Then, multivariate log-binomial regression models were used to assess the association between low back symptoms and exposure variables (vibration and postural load) while controlling for the influence of potential confounding factors. Both exposure variables and confounding factors were entered in the log-binomial model as categorical covariates, except for age, which was used as a continuous covariate. Two-factor product terms were included in the model to assess the interaction between exposure variables and other covariates. The significance of additional variables in the model was tested by the likelihood ratio statistic. Independent variables were retained in the model when their probability value was $<0{\cdot}15$. Age was included in each model regardless of the level of statistical significance.

3. RESULTS

3.1. VIBRATION MEASUREMENTS

Table 1 reports the mean (SD) values of the frequency-weighted r.m.s. accelerations measured on the seatpan of the port machines and vehicles. The *z*-axis (vertical) weighted acceleration was the predominant directional component of vibration measured on the fork-lift trucks and the straddle carriers. In the cranes, similar weighted acceleration magnitudes were recorded along the three orthogonal axes. The average vibration total value (vector sum) of the weighted r.m.s. accelerations was greater for the fork-lift trucks (0·90 m/s^2) than for the straddle carriers (0·48 m/s^2) or the cranes (0·22–0·53 m/s^2). Frequency analysis showed that the vibration frequencies with the highest r.m.s. accelerations were 1·6–2 Hz (*z*-axis) for the straddle carriers, 2–5 Hz (*z*-axis) for the fork-lift trucks, and 1·25–4 Hz (*x*- and *z*-axis) for the cranes.

3.2. CHARACTERISTICS OF THE STUDY GROUPS

Preliminary data analysis showed marginal, even though significant, differences between the several study groups with respect to age, total length of employment in previous and

TABLE 1

Frequency-weighted root-mean-square (r.m.s.) acceleration magnitude (a_w) of vibration measured in the x-, y-, and z-axis on the seat of port machines. The vector sum of the frequency-weighted r.m.s. accelerations (a_v) is calculated according to International Standard ISO 2631-1 (1997). *Data are given as means* (SD)

Machines	*N*	a_{wy} (m/s^2)	a_{wx} (m/s^2)	a_{wz} (m/s^2)	a_v (m/s^2)
Straddle carriers	7	0·23 (0·04)	0·08 (0·05)	0·33 (0·03)	0·48 (0·07)
Fork-lift trucks	7	0·35 (0·33)	0·18 (0·15)	0·64 (0·59)	0·90 (0·77)
Mobile cranes	2	0·21 (0·18)	0·37 (0·26)	0·32 (0·28)	0·53 (0·27)
Overhead cranes	2	0·07 (0·02)	0·11 (0·03)	0·11 (0·09)	0·22 (0·12)

Table 2

Characteristics of the study populations. Data are given as means (SD) *or numbers* (%)

	Controls ($n = 85$)	Straddle carrier drivers ($n = 85$)	Fork-lift truck drivers ($n = 88$)	Crane operators ($n = 46$)
Age (yr)	40·6 (5·0)	38·1 (4·5)	41·5 (4·3)	39·0 (4·3)†
Height (cm)	178 (6·2)	177 (5·7)	176 (6·6)	178 (6·8)
Weight (kg)	85·8 (14·2)	81·9 (10·8)	81·1 (11·5)	85·5 (12·9)‡
BMI (kg/m^2)	27·1 (3·8)	26·0 (3·2)	26·2 (3·2)	26·8 (3·6)
Smokers (*n*)	37 (43·5)	36 (42·4)	49 (55·7)	31 (67·4)§
Drinkers (*n*)	52 (61·2)	59 (69·4)	54 (61·4)	29 (63·0)
Total length of employment (yr)	20·3 (4·7)	18·6 (4·9)	21·8 (3·7)	20·6 (4·6)†
Length of employment in driving (yr)	—	8·2 (5·2)	10·5 (7·0)	9·4 (6·0)
Equivalent vibration magnitude (m/s^2 r.m.s.)	—	0·49 (0·15)	0·92 (0·31)	0·46 (0·25)†
Cumulative vibration exposure (yr m^2/s^4)	—	2·3 (2·9)	9·2 (12·2)	2·0 (2·2)†

BMI: body mass index.
†*F*-test (one-way ANOVA): $p < 0{\cdot}01$.
‡*F*-test (one-way ANOVA): $p < 0{\cdot}05$.
§Chi-square test: $p < 0{\cdot}05$.

current companies, and smoking habit ($p < 0{\cdot}05$) (see Table 2). Body mass index, drinking habit, and some sociocultural factors (education, marital status, sport activity) were similar in the four occupational groups. In the port machinery operators, there was no difference in the length of employment as vehicle drivers or crane operators. Occupational exposure to WBV in terms of both equivalent vibration magnitude and cumulative vibration exposure was significantly greater in the fork-lift drivers than in the straddle carrier drivers and the crane operators ($p < 0{\cdot}001$). The distribution of previous jobs with heavy physical demands did not differ among the groups (results not shown).

3.3. LOW BACK PAIN, BACKGROUND FACTORS, AND PROFESSIONAL GROUPS

Univariate analysis showed that in the overall study population there was no clear association between lifetime LBP and age, while the 12-month prevalence of LBP tended to increase, even though not significantly, with the increase of age (see Table 3). After adjustment for age, the period prevalence of LBP was not found to be related to some individual characteristics such as smoking habit, education, marital status, sport activity, or annual amount of car driving. Significant associations were observed between the various time-related LBP and occupation, cumulative vibration exposure, and perceived postural load. Back trauma was an important predictor of the occurrence of LBP in the past (age-adjusted *PR*: 1·29; 95% *CI*: 1·17–1·44) and the previous 12 months (age-adjusted *PR*: 1·52; 95% *CI*: 1·29–1·79). Climatic working conditions (low temperature, draught) were not associated with low back symptoms in both the control manual workers and the port machinery operators. Perceived mental stress during driving of vehicles or operating cranes

TABLE 3

Age-adjusted prevalence ratios (PR) and 95% confidence intervals (95% CI) for lifetime and 12-month prevalence of low back pain (LBP) according to various individual and work-related risk factors

Factor	Lifetime LBP		12-month LBP	
	PR	(95% *CI*)	*PR*	(95% *CI*)
Age (years)				
< 38	1·0	(—)	1·0	(—)
38–42	1·10	(0·96–1·27)	1·16	(0·93–1·46)
> 42	1·03	(0·88-1·21)	1·19	(0·94–1·50)
Occupation				
Controls	1·0	(—)	1·0	(—)
Machinery operators	1·20	(1·02–1·40)	1·23	(0·98–1·54)
Cumulative vibration exposure (yr m^2/s^4)				
0	1·0	(—)	1·0	(—)
< 1	1·21	(1·00–1·46)	1·22	(0·93–1·61)
1–4	1·21	(1·01–1·45)	1·08	(0·82–1·43)
> 4	1·22	(1·01–1·46)	1·35	(1·06–1·72)
Postural load (grades)				
Mild	1·0	(—)	1·0	(—)
Moderate	1·06	(0·85–1·33)	1·37	(0·92–2·02)
Hard	1·22	(0·99–1·52)	1·79	(1·23–2·60)
Very hard	1·30	(1·06–1·60)	2·03	(1·41–2·93)
Back trauma				
No	1·0	(—)	1·0	(—)
Yes	1·29	(1·17–1·44)	1·52	(1·29–1·79)
Body mass index (kg/m^2)				
< 25	1·0	(—)	1·0	(—)
25–27·5	1·14	(0·98–1·32)	1·30	(1·03-1·64)
> 27·5	1·08	(0·92–1·26)	1·27	(0·99–1·61)
Education (years)				
< 6	1·0	(—)	1·0	(—)
6–8	0·93	(0·80–1·07)	0·84	(0·68–1·03)
> 8	0·88	(0·73–1·06)	0·78	(0·59–1·03)
Sport activity				
No	1·0	(—)	1·0	(—)
1–4 h per week	1·12	(0·90–1·39)	1·19	(0·86–1·65)
> 4 h per week	1·13	(0·95–1·36)	1·19	(0·91–1·56)
Smoking status				
No	1·0	(—)	1·0	(—)
Yes	0·99	(0·87–1·13)	1·03	(0·86–1·23)
Marital status				
Single	1·0	(—)	1·0	(—)
Married/cohabiting	0·98	(0·83–1·16)	0·96	(0·74–1·24)
Divorced/separated	0·85	(0·64–1·11)	0·99	(0·70–1·40)
Car driving (km per year)				
< 5000	1·0	(—)	1·0	(—)
5000–15 000	0·97	(0·82–1·15)	1·03	(0·78–1·36)
> 15 000	0·97	(0·80–1·18)	1·05	(0·77–1·42)

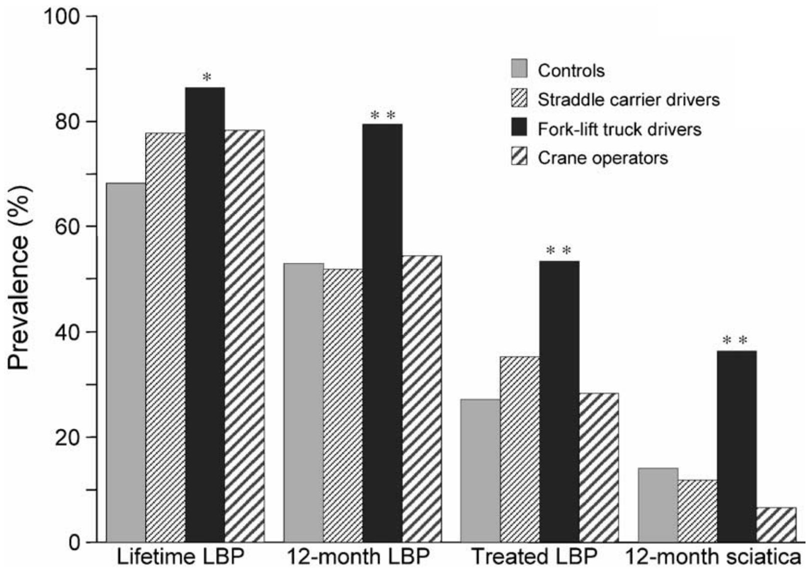

Figure 1. Period prevalence of low back pain (LBP), treated LBP and sciatica among the controls and the port machinery operators according to their job titles. Chi-square test: *$p < 0{\cdot}05$; **$p < 0{\cdot}001$.

was found to be significantly related to LBP and treated LBP in the last 12 months ($p < 0{\cdot}01$).

Figure 1 shows the distribution of several types of low back symptoms in the four occupational groups. The crude prevalence of LBP during lifetime and that of LBP, treated LBP, and sciatic pain in the last 12 months were significantly greater in the fork-lift truck drivers than in the other groups ($0{\cdot}001 < p < 0{\cdot}05$). No difference in the occurrence of low back symptoms was found between the straddle carrier drivers, the crane operators, and the control manual workers. These findings were confirmed by a multivariate analysis (see Table 4); when compared with the controls and while controlling for potential confounders by log-binomial regression modelling, only in the group of the fork-lift truck drivers did the adjusted prevalence ratios (*aPR*) significantly exceed unity for almost all low back symptoms (*aPR*: 1·25–2·40). An excess risk for lumbar disc herniation was also found in the fork-lift truck drivers, but the association was not significant (*aPR*: 1·58; 95% *CI*: 0·75–3·31). Symptoms of sciatica were associated with a radiological diagnosis of lumbar disc herniation in both the controls ($p < 0{\cdot}01$) and the port machinery operators ($p < 0{\cdot}001$). In the last 12 months, the duration of LBP and sick leave due to LBP were longer in the fork-lift truck drivers than in the controls and the other port machinery operators (see Table 5). Moreover, the fork-lift truck drivers consulted a doctor or a physiotherapist and used medicines or physical therapy for back problems more frequently than the other occupational groups ($0{\cdot}005 < p < 0{\cdot}03$).

3.4. LOW BACK PAIN AND VIBRATION EXPOSURE

When the port machinery operators were divided into three categories of increasing WBV exposure and the controls were assumed as the reference category, significantly increased adjusted prevalence ratios for low back symptoms were found for the highest

TABLE 4

Prevalence ratios† (95% *confidence interval*) *for low back pain* (*LBP*), *sciatica*, *and lumbar disc herniation in the port machinery operators compared with the controls*

Symptoms	Straddle carrier drivers ($n = 85$)	Fork-lift truck drivers ($n = 88$)	Crane operators ($n = 46$)
LBP, lifetime prevalence	1·12 (0·93–1·35)	1·25 (1·05–1·48)	1·14 (0·92–1·41)
LBP, 12-month prevalence	0·92 (0·69–1·23)	1·42 (1·13–1·78)	0·96 (0·68–1·35)
Sciatica, 12-month prevalence	0·74 (0·33–1·67)	2·40 (1·32–4·38)	0·45 (0·13–1·52)
Treated LBP	1·12 (0·72–1·74)	1·77 (1·20–2·61)	0·97 (0·55–1·71)
Sick leave due to LBP (> 14 days)	0·69 (0·33–1·42)	2·12 (1·22–3·68)	0·86 (0·38–1·95)
Lumbar disc herniation‡	0·49 (0·20–1·25)	1·58 (0·75–3·31)	0·58 (0·18–1·89)

†Prevalence ratios adjusted for age and other covariates (body mass index, smoking habit, mental stress on current job, and back trauma) by fitting log-binomial regression models.
‡Adjusted for age, body mass index, and back trauma.

TABLE 5

Duration of low back pain (*LBP*), *health care use and sick leave because of LBP during the previous* 12 *months among the controls and the port machinery operators. Data are given as numbers* (%)

	Controls ($n = 85$)	Straddle carrier drivers ($n = 85$)	Fork-lift truck drivers ($n = 88$)	Crane operators ($n = 46$)
Number of days with LBP†				
0	40 (47·1)	41 (48·2)	18 (20·5)	22 (47·8)
1–7	6 (7·1)	10 (11·8)	15 (17·1)	3 (6·5)
8–30	10 (11·8)	10 (11·8)	12 (13·6)	7 (15·2)
More than 30, not daily	25 (29·4)	21 (24·7)	35 (39·7)	12 (26·1)
Daily	4 (4·7)	3 (3·5)	8 (9·1)	2 (4·4)
Visit to a doctor or physiotherapist†				
No	61 (71·8)	63 (74·1)	48 (54·6)	35 (76·1)
Yes	24 (28·2)	22 (25·9)	40 (45·4)	11 (23·9)
Medication and/or physical therapy‡				
No	62 (72·9)	55 (64·7)	41 (46·6)	33 (71·7)
Yes	23 (27·1)	30 (35·3)	47 (53·4)	13 (28·3)
Sick leave (days)‡				
0	71 (83·5)	74 (87·1)	56 (63·6)	39 (84·8)
1–7	4 (4·7)	2 (2·4)	14 (15·9)	1 (2·2)
8–30	5 (5·9)	3 (3·5)	10 (11·4)	4 (8·7)
> 30	5 (5·9)	6 (7·1)	8 (9·1)	2 (4·4)

†Chi-square test: $p < 0{\cdot}03$.
‡Chi-square test: $p < 0{\cdot}005$.

category of duration of exposure (> 12 driving years, see Table 6), equivalent vibration magnitude (> 0·79 m/s^2 r.m.s., see Table 7), and cumulative vibration exposure (> 4 yr m^2/s^4, see Table 8). After controlling for potential confounders, high prevalence

TABLE 6

Prevalence ratios† (95% *confidence interval*) *for low back pain* (*LBP*), *sciatica, and lumbar disc herniation in the port machinery operators divided into categories of duration of exposure* (*driving years*), *compared with the controls*

	Duration of exposure (driving years)		
Symptoms	1–6 ($n = 81$)	6–12 ($n = 72$)	> 12 ($n = 66$)
LBP, lifetime prevalence	1·14 (0·97–1·35)	1·10 (0·92–1·33)	1·21 (1·04–1·42)
LBP, 12-month prevalence	1·25 (0·98–1·59)	1·11 (0·85–1·45)	1·27 (1·04–1·56)
Sciatica, 12-month prevalence	1·26 (0·63–2·52)	1·29 (0·61–2·70)	2·31 (1·28–4·19)
Treated LBP	1·26 (0·81–1·96)	1·24 (0·80–1·92)	1·55 (1·02–2·34)
Sick leave due to LBP (> 14 days)	0·76 (0·36–1·63)	1·08 (0·53–2·22)	2·11 (1·15–3·87)
Lumbar disc herniation‡	1·31 (0·66–2·61)	1·07 (0·50–2·28)	1·23 (1·08–1·39)

†Prevalence ratios adjusted for age and other covariates (body mass index, smoking habit, mental stress on current job, back trauma, and postural load) by fitting log-binomial regression models.
‡Adjusted for age, body mass index, back trauma, and postural load.

TABLE 7

Prevalence ratios† (95% *confidence interval*) *for low back pain* (*LBP*), *sciatica, and lumbar disc herniation in the port machinery operators divided into categories of equivalent vibration magnitude* (m/s^2 r.m.s.), *compared with the controls*

	Equivalent vibration magnitude (m/s^2 r.m.s.)		
Symptoms	< 0·46 ($n = 81$)	0·46–0·79 ($n = 92$)	> 0·79 ($n = 46$)
LBP, lifetime prevalence	1·22 (1·05–1·42)	1·10 (0·93–1·30)	1·16 (0·98–1·38)
LBP, 12-month prevalence	1·04 (0·82–1·33)	1·11 (0·89–1·38)	1·24 (1·01–1·53)
Sciatica, 12-month prevalence	0·66 (0·27–1·57)	1·42 (0·75–2·69)	1·55 (0·77–3·13)
Treated LBP	1·17 (0·75–1·84)	1·33 (0·89–2·01)	1·58 (1·04–2·42)
Sick leave due to LBP (> 14 days)	0·93 (0·47–1·86)	1·23 (0·67–2·27)	1·84 (1·00–3·42)
Lumbar disc herniation‡	0·62 (0·21–1·81)	1·16 (0·49–2·74)	1·27 (0·47–3·41)

†Prevalence ratios adjusted for age and other covariates (body mass index, smoking habit, mental stress on current job, back trauma, and postural load) by fitting log-binomial regression models
‡Adjusted for age, body mass index, back trauma, and postural load

ratios for 12-month sciatica were observed for both duration of exposure to WBV (*aPR*: 2·31; 95% *CI*: 1·28–4·19) and cumulative vibration exposure (*aPR*: 1·99; 95% *CI*: 1·05–3·75). The prevalence of treated LBP and sick leave caused by LBP (> 14 days) during the previous 12 months was significantly associated with all the three indices of WBV exposure. A significant excess risk for lumbar disc herniation (*aPR*: 1·23; 95% *CI*: 1·08–1·39) was observed only in the port machinery operators with prolonged driving experience. When the controls were excluded from the analysis, trend statistics showed that the occurrence of sciatic pain and sick leave due to LBP in the last 12 months significantly increased with the increase of either duration of exposure ($0{\cdot}005 < p < 0{\cdot}03$) or cumulative vibration exposure ($0{\cdot}01 < p < 0{\cdot}05$) included as continuous variables in log-binomial regression models.

TABLE 8

Prevalence ratios† (95% *confidence interval*) *for low back pain* (*LBP*), *sciatica, and lumbar disc herniation in the port machinery operators divided into categories of cumulative vibration exposure* (yr m^2/s^4), *compared with the controls*

	Cumulative vibration exposure (year m^2/s^4)		
Symptoms	< 1 ($n = 65$)	1–4 ($n = 79$)	> 4 ($n = 75$)
LBP, lifetime prevalence	1·10 (0·94–1·31)	1·09 (0·93–1·28)	1·19 (1·03–1·37)
LBP, 12-month prevalence	1·07 (0·83–1·39)	0·99 (0·76–1·28)	1·27 (1·02–1·58)
Sciatica, 12-month prevalence	0·53 (0·20–1·43)	1·57 (0·81–3·05)	1·99 (1·05–3·75)
Treated LBP	1·28 (0·84–1·94)	1·00 (0·64–1·54)	1·56 (1·08–2·25)
Sick leave due to LBP (> 14 days)	0·77 (0·36–1·67)	1·17 (0·62–2·20)	1·77 (1·01–3·13)
Lumbar disc herniation‡	0·77 (0·27–2·24)	0·87 (0·33–2·28)	1·29 (0·54–3·08)

†Prevalence ratios adjusted for age and other covariates (body mass index, smoking habit, mental stress on current job, back trauma, and postural load) by fitting log-binomial regression models.
‡Adjusted for age, body mass index, back trauma, and postural load.

3.5. LOW BACK PAIN AND PERCEIVED POSTURAL LOAD

Prolonged sitting posture during work was not found to be related to either LBP or sciatic pain (see Table 9). The 12-month prevalence of LBP and sciatica tended to increase with the frequency of non-neutral trunk postures at work (bending forward and twisting), but the association was significant only for LBP. On the contrary, high frequencies of lifting were strongly associated with the occurrence of sciatic pain (*aPR*: 5·29–6·79), while the association with LBP was less evident (*aPR*: 1·12–1·18). After adjusting for individual variables and vibration exposure, the prevalence ratios for low back symptoms tended to increase with increase of perceived postural load (see Table 10). Lumbar intervertebral disc herniation showed no association with postural load. No significant interaction between postural load and vibration exposure was observed when a two-product term for these variables was added to log-binomial regression models. When the controls and the port machinery operators were examined separately, both groups showed a linear trend of increasing prevalence of LBP with increasing postural load expressed on an ordinal scale ($p < 0{\cdot}01$).

4. DISCUSSION

In this study, the cumulative lifetime occurrence of LBP was significantly greater in port machinery operators exposed to WBV and postural load than in control men performing heavy physical work. However, when the period prevalence of LBP was restricted to the last 12 months, low back symptoms occurred more frequently in the fork-lift truck drivers than in the other occupational groups. In this investigation, vibration exposure in terms of duration and magnitude was stronger in the fork-lift truck drivers than in the straddle carrier drivers and the crane operators. This finding is consistent with the results of a recent national survey of occupational exposure to WBV in Great Britain [17]. This survey pointed out that professional fork-lift truck drivers were the occupational group with the highest exposure to WBV expressed as vibration dose value, a measure of daily vibration

TABLE 9

Prevalence ratios (PR)[†] *and 95% confidence intervals (95% CI) for 12-month prevalence of low back pain (LBP) and sciatica according to postural risk factors*

Factor	12-month LBP *PR*	12-month LBP (95% *CI*)	12-month sciatica *PR*	12-month sciatica (95% *CI*)
Sitting (h/day)				
< 1	1·0	(—)	1·0	(—)
1–4	1·12	(0·85–1·49)	0·96	(0·46–2·03)
> 4	1·22	(0·93–1·62)	1·21	(0·59–2·49)
Lifting > 10 kg (frequency)				
Seldom	1·0	(—)	1·0	(—)
Sometimes	0·93	(0·66–1·30)	2·85	(0·64–12·7)
Often	1·12	(0·80–1·57)	5·29	(1·17–23·8)
Very often	1·18	(0·87–1·60)	6·79	(1·55–29·8)
Bending forward (frequency)				
Seldom	1·0	(—)	1·0	(—)
Sometimes	2·32	(0·72–7·44)	2·87	(0·34–24·2)
Often	3·44	(1·15–10·3)	2·19	(0·26–18·5)
Very often	4·00	(1·36–11·8)	2·03	(0·25–16·3)
Twisting (frequency)				
Seldom	1·0	(—)	1·0	(—)
Sometimes	1·32	(0·36–4·31)	1·12	(0·13–8·75)
Often	1·88	(0·75–5·81)	1·34	(0·20–10·8)
Very often	2·15	(1·02–6·21)	2·01	(0·37–14·5)
Combined postural load (grades)				
Mild	1·0	(—)	1·0	(—)
Moderate	1·38	(0·92–2·06)	1·26	(0·42–3·81)
Hard	1·81	(1·25–2·62)	2·68	(0·96–7·52)
Very hard	1·98	(1·38–2·85)	3·71	(1·36–10·1)

[†]Prevalence ratios adjusted for age and other covariates (body mass index, mental stress on current job, back trauma, and cumulative exposure to vibration) by fitting log-binomial regression models. Prevalence ratios for postural risk factors are mutually adjusted.

TABLE 10

Prevalence ratios[†] *(95% confidence interval) for low back pain (LBP), sciatica, and lumbar disc herniation according to perceived postural load*

Symptoms	Postural load (grades): 1 (mild)[§] ($n = 52$)	2 (moderate) ($n = 99$)	3 (hard) ($n = 80$)	4 (very hard) ($n = 73$)
LBP, lifetime prevalence	1·0 (—)	1·09 (0·86–1·37)	1·26 (1·02–1·56)	1·31 (1·06–1·61)
LBP, 12-month prevalence	1·0 (—)	1·38 (0·92–2·06)	1·81 (1·25–2·62)	1·98 (1·38–2·85)
Sciatica, 12-month prevalence	1·0 (—)	1·26 (0·42–3·81)	2·68 (0·96–7·52)	3·71 (1·36–10·1)
Treated LBP	1·0 (—)	2·44 (1·17–5·09)	2·74 (1·32–5·68)	3·36 (1·65–6·84)
Sick leave due to LBP (> 14 days)	1·0 (—)	1·88 (0·73–4·84)	2·83 (1·13–7·10)	3·11 (1·23–7·83)
Lumbar disc herniation[‡]	1·0 (—)	0·88 (0·28–2·80)	1·56 (0·53–4·60)	0·61 (0·18–2·09)

[†]Prevalence ratios adjusted for age and other covariates (body mass index, smoking habit, mental stress on current job, back trauma, and cumulative vibration exposure) by fitting log-binomial regression models.
[‡]Adjusted for age, body mass index, back trauma, and cumulative vibration exposure.
[§]Reference category.

exposure based on the "fourth power" method and included in both the British Standard 6841 [18] and the International Standard ISO 2631–1 [13]. In previous surveys, frequency-weighted r.m.s. acceleration magnitudes between 0·5 and 1·6 m/s^2 have been measured in samples of fork-lift trucks used in several industrial activities [19, 20]. Our findings on WBV exposure in the fork-lift truck drivers are similar to those reported in an epidemiological study carried out in six harbour companies in The Netherlands [21]. The investigators found that the vector sum of the frequency-weighted accelerations was 0·8 m/s^2 for their fork-lift trucks (0·9 m/s^2 in the present study) and the estimated cumulative vibration exposure was 10·5 yr m^2/s^4 for their fork-lift truck drivers (9·2 yr m^2/s^4 in the present study). In the Dutch study, younger drivers ($<$ 35 yr) reported a higher prevalence of (low) back pain than the control subjects, whereas older drivers ($>$ 45 yr) showed no difference when compared with a reference group, probably because of health-based selection. In another survey of fork-lift truck drivers employed at a chemical company, the same investigators found an excess risk of (low) back symptoms in the drivers and an increasing prevalence of LBP with increasing cumulative vibration exposure [21]. Similar findings have been reported in two epidemiological studies of fork-lift truck drivers carried out in Denmark and Germany [22, 23]. Brendstrup and Biering-Sørensen [22] observed a higher occurrence of lifetime and 12-month LBP in 169 male fork-lift truck drivers from 13 Danish companies than in a group of 399 working men representative of the general population. Moreover, the drivers showed a greater absence from work due to LBP and an increase in the occurrence of low back troubles with the increase of length of employment (driving years). In Germany, Schwarze *et al.* [23] made a medical diagnosis 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") in 65% of 159 drivers of fork-lift trucks exposed to 8-h energy-equivalent frequency-weighted acceleration magnitude [A(8)] of 0·45 m/s^2 (range 0·13–1·12 m/s^2). In their cohort which included fork-lift truck drivers, truck drivers and operators of heavy machinery, the German authors reported an increased 4-yr incidence of lumbar syndrome among drivers exposed to A(8) greater than 0·6 m/s^2. These epidemiological investigations tend to support the findings of the present study which suggest that fork-lift truck drivers represent an occupational group at high risk for low back disorders. The results of multivariate analysis also suggest that long-term exposure to intense WBV and excessive postural load may have contributed to the excess risk of LBP observed in the drivers of fork-lift trucks.

In the currently available epidemiological literature, there is only one study which investigated the prevalence of LBP in drivers of straddle carriers [24]. In this study, 95 straddle carrier drivers employed at a transport company in the port of Rotterdam showed a significantly high odds ratio for newly developed cases of LBP in their current job when compared with a group of office workers. This finding seems to be in disagreement with the results of the present study in which no increased risk for LBP was found in the straddle carrier drivers compared with a group of manual workers. Since the magnitude and duration of WBV exposure were similar for the straddle carrier drivers of the two studies, it is very likely that differences in the working conditions between the two control groups (office *versus* manual workers), as well as in their 12-month prevalence of LBP (34 in the office workers *versus* 53% in the manual workers), can account, at least partially, for the discrepancy in the risk estimates between the two studies. Moreover, owing to the cross-sectional design of our investigation, we cannot exclude a possible role of the "healthy worker effect" in the underestimation of the risk for LBP among the straddle carrier drivers.

Epidemiological studies of LBP in crane operators have given rise to contrasting findings. In some cross-sectional surveys, an elevated risk for LBP has been found among crane operators compared with control workers engaged in either sedentary occupations or manual activities [24, 25]. In these studies, the 12-month prevalence of LBP was comparable to that found in the crane operators of the present investigation (40–60%), while the frequency of LBP reported by the controls was lower (27–34%) than that observed in our control manual workers (53%). In an Italian cross-sectional study of 78 crane operators working in the Port of Venice, the overall prevalence of disorders in the lumbar spine was 38·5%, but this figure was not significantly higher than that observed in an age-matched control group arising from the general population [26]. In a series of retrospective cohort studies, Bongers *et al.* [27–29] investigated the incidence of work disability and sickness absence due to (low) back disorders in large samples of workers operating cranes in industry. Using social insurance health records as the source of medical information, a significantly increased incidence density ratio for disability pension due to intervertebral disc disorders was found in 743 crane operators of a steel company compared with controls made up of maintenance operators and manual workers [27]. However, no increase in the risk for long-term sickness absence ($\geqslant$ 28 days) due to spondyloarthrosis, intervertebral disc disorders, and other unspecified back disorders was observed in the same group of crane operators during a retrospective 10-yr follow up period [28]. In a further retrospective (40-yr) cohort study, the Dutch researchers found no excess risk of permanent work disability caused by back disorders in a group of 341 crane operators employed in a metal construction company, when compared with a reference group of metal workers, fitters, and mechanics [29]. The findings of these epidemiological studies seem to suggest that there is no clear association between (low) back disorders and work on a crane in several industrial activities. This may be due to differences between the various studies with respect to the study design, the characteristics of the study populations, the selection of the control groups, the definition of the health outcomes, and the assessment of exposure to work-related risk factors.

In this study, several types of low back complaints were significantly associated with a measure of cumulative vibration exposure estimated according to an "energy-equivalent" time dependency suggested in current standards for whole-body vibration [13]. The association was evident mainly in the port machinery operators with prolonged driving experience. Both components of cumulative vibration exposure, i.e., vibration magnitude and exposure duration, were associated with low back symptoms but the duration of exposure to WBV was related to LBP more than the estimated equivalent vibration magnitude. This finding is consistent with those of previous epidemiological studies of tractor drivers in which the total duration of exposure to WBV was found to contribute more than equivalent vibration magnitude to the overall association between accumulated vibration dose and LBP [15, 30].

In the port machinery operators of this study, quantitative regression analysis showed a significant trend of increasing occurrence of sciatic pain and sickness absence due to LBP with the increase of either exposure duration or cumulative vibration exposure. This finding suggests an exposure–response relationship for selected low back complaints among the port machinery operators. Nevertheless, a lower risk of sciatica, sick leave due to LBP and lumbar disk herniation was observed in the group of port machinery operators included in the lowest category of equivalent vibration magnitude and cumulative vibration exposure. Since lifting and carrying were found to be more frequent in the control group, this pattern may be explained by residual confounding from ergonomic exposures, despite attempts to adjust for postural load.

The evidence of an excess risk for sciatic pain in our WBV exposed workers, as well as its association with disc herniation, seems to be consistent with the results of a recent cross-sectional magnetic resonance imaging study of low back symptoms in relation to lumbar disc degeneration and occupation [31]. In this study, LBP and sciatic pain were found to be significantly associated with signs of degeneration of discs L2/L3 and L5/S1, and the profession of machine driver was a strong predictor of sciatic pain (odds ratio: 6·4), when compared with office workers. The investigators suggested that exposure to WBV and prolonged constrained sitting could account for the high prevalence of sciatic pain among the machine drivers.

Our study has pointed out a strong association between low back symptoms and awkward postures at work in both the control manual workers and the port machinery operators. Prolonged seated posture was common among all operators of machines and vehicles, bending forward prevailed in the straddle carrier drivers and the crane operators, and twisting of the spine was more frequently observed in the fork-lift truck drivers. It is worth noting that sitting posture as an individual variable was not found to be associated with LBP. This is consistent with the finding that sitting-while-working is poorly correlated with LBP [32], while prolonged static postures combined with WBV exposure and frequent twisting of the spine, as occurs while driving, are associated with LBP, sciatica, and disc herniation more strongly than sedentary or dynamic physical work [8, 33].

In this study, the methods of assessment of vibration exposure and postural load were not fully comparable because vibration exposure was estimated from objective measurements, whereas postural load 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. Since the association between LBP and postural load was evaluated mainly on the basis of self-reported working postures, potential bias for spurious associations because of a low threshold in reporting both 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 [16, 34]. Moreover, ergonomic investigations have shown a good agreement between self-reported and observed frequency, duration, and magnitude of physical demands [35]. Although the role of the questionnaire as an instrument for assessing occupational physical stressors is still controversial [36–38], questionnaire methods may offer benefits for studying cumulative exposure over time, a variable which cannot be estimated by direct observations or measurements [39].

Multivariate analysis showed that WBV exposure and postural load were independent contributors to the occurrence of low back symptoms in the port machinery operators. This finding seems to be supported by the experimental evidence that concomitant exposure to WBV and awkward posture can give rise to an excess of compressive load and shear stress on soft and bone tissues of the spine [40–42]. Moreover, frequency analysis of the vibration recorded on the seats of port machines and vehicles showed acceleration peaks at the frequencies of 1·25–5 Hz. Biodynamic experiments have shown that in a seated subject exposed to vertical vibration the lumbar tract of the spine has a resonance in the frequency range between 2 and 6 Hz [41, 42]. Since under resonance large relative displacements between the lumbar vertebrae take place, it is likely that the lumbar spine of the port machinery operators was overloaded by mechanical vibration during operating conditions.

Ergonomic analysis of work conditions showed that the control subjects of this study were exposed to postural risk factors. Manual materials handling (lifting or carrying loads) was predominant in the control workers compared with the WBV exposed operators. Epidemiological studies have proved that manual materials handling is associated with work-related back disorders [8, 9]. Consistently, we found that perceived postural load was significantly related to the occurrence of LBP in our control manual workers. They also reported low back symptoms more frequently than did control groups used in other epidemiological studies [24, 25]. This may have reduced the estimates of the risk for LBP in the various groups of port machinery operators. We recognize that there were differences in the exposure to physical load risk factors between the controls and the port machinery operators. Despite these limitations, our study benefited from the advantage that the two groups were employed at the same company and that they were comparable with respect to some personal, socio-economic and cultural characteristics which are known to influence the onset of back disorders. On the other hand, the selection of appropriate control groups in epidemiological studies of work-related (low) back pain is still a matter of uncertainty among the investigators.

In this study, daily vibration exposure in terms of $A(8)$ averaged 0·64 m/s^2 for the fork-lift truck drivers, 0·34 m/s^2 for the straddle carrier drivers, and 0·27 m/s^2 for the crane operators. In an Annex to a proposal of Directive on physical agents prepared by the Council of the European Union in 1994 [43], an "action value" of 0·5 m/s^2, expressed as $A(8)$, has been suggested for the risk of "low back morbidity and trauma of the spine" resulting from exposure to whole-body vibration. For exposures exceeding the "action value", worker information and training, assessment of the vibration, technical measures and health surveillance should be implemented. The proposal of Council Directive is currently under revision and changes in the "exposure action value" have been suggested by some Member States. Even though the cross-sectional design of the present study does not permit firm conclusions on the relationship between WBV exposure and LBP disorders, nevertheless our findings indicate that the fork-lift truck drivers are at high risk for low back troubles when compared with manual workers exposed to heavy physical load but not exposed to vibration. Exposure and health effect data in the fork-lift truck drivers of this study suggest that an $A(8)$ of 0·5 m/s^2 may be a reasonable "action value" aimed at identifying work conditions in which a programme of protective and preventive measures should be established to reduce the risk of long-term adverse health effects on the lower back of professional drivers.

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