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ScienceDirect
Journal of Sound and Vibration 298 (2006) 540–555
JOURNAL OF SOUND AND VIBRATION
www.elsevier.com/locate/jsvi

Low back pain in drivers: The relative role of whole-body vibration, posture and manual materials handling

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Received 2 May 2006; received in revised form 11 May 2006; accepted 8 June 2006
Available online 10 August 2006

Abstract

A cross-sectional study was conducted to investigate the relative role of whole-body vibration (WBV), posture and manual materials handling (MMH) as risk factors for low back pain (LBP). Using a validated questionnaire, information about health history, posture and MMH performed was obtained from 394 workers who drove vehicles as part of their job (according to seven predefined occupational groups) and 59 who did not. The intention was to reflect a wide range of exposures with the lower end of the exposure spectrum defined as that of non-manual workers who do not drive as part of their job. Based on the questionnaire responses and direct measurements of vibration exposure, personal aggregate measures of exposure were computed for each of the respondents, i.e., total vibration dose (TVD), posture score (PS) and manual handling score (MHS). Odds ratios (and 95% confidence intervals) for back pain were obtained from logistics regression models and log-linear backward elimination analysis was performed. The findings showed that 'combined exposure' due to posture and one or both of vibration and MMH, rather than the individual exposure to one of the three factors (WBV, posture, MMH) is the main contributor of the increased prevalence of LBP.

1. Introduction

Exposure to whole-body mechanical vibration (vibration) is now widely recognised as associated with musculoskeletal disorders of the spinal system amongst occupational drivers, with the most frequently reported adverse effects being low back pain (LBP), early degeneration of the spine and herniated intervertebral discs (nucleus pulposus—HNP) [1–3].

During their work, drivers spend majority of the time seated. Inclination of the seat and its height from ground level, position and shape of the backrest and the presence of armrests all contribute to influence the seated posture adopted. Considering that all postures become uncomfortable if maintained for long periods at a time, the seat should permit regular alterations of position. Froom et al. [4] assessed the effect of helicopter crew sitting positions (gunner and pilot) on the prevalence of LBP during flight and found that a vertical

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0022-460X/$ - see front matter
doi:10.1016/j.jsv.2006.06.007

sitting position was adopted by the gunner, whereas the pilot showed to lean forward and to the left in order to operate the controls. The pilot positions associated with an increased prevalence of pain as well as earlier onset and increased intensity of pain. It may then be that back pain occurrences amongst drivers are encouraged more by the combined effect of seated posture and vibration rather than vibration or seated posture alone. Indeed, both vibration and the seated posture (relative to the standing posture), particularly twisted and bent positions, have been shown to increase the pressure in and loading on the disc [5,6].

The risks from vibration and posture may be further compounded when manual materials handling (MMH) is also performed. Firstly, the back muscles can become fatigued during driving due to the vehicular vibrations, and thereby become less able to react to further loading [7]. Secondly, the discs undergo creep or loss of height from vibration, thereby becoming stiffer and the motion segments exhibit a decreased capacity to dissipate energy as well as decreased ultimate strength when placed under a compressive load [8,9]. These two factors put the spine in a condition of increased risk of injury when loads are handled after driving. It is well established that frequent MMH, especially repetitive lifting, is an important risk factor associated with severe and disabling LBP [10].

The objective of this work was to investigate the relative role of whole-body vibration (WBV), posture and MMH as risk factors for LBP. There were two specific aims:

(a) To assess for different groups of occupational drivers the exposures to WBV, posture and MMH;
(b) To determine the relative importance, of each factor (independently and in combination), as risk factors for LBP.

2. Subjects and methods

The study comprised of a cross-sectional self-assessment questionnaire survey, and included respondents who had spent at least one complete year in present job or had at least 5 years driving experience in current and immediate past job. Persons who drove any type of motor vehicle or operated heavy machinery as part of their current job represented the source population from which the study sample was drawn, which included different organisations or employment affiliations and eight occupational groups (as listed in Table 1). The intention was to reflect a wide range of exposures with the lower end of the exposure spectrum defined as that of persons who are non-manual workers and do not drive as part of their job. Inclusion criteria were only in respect of vibration exposure. Though the study group included both men and women, the number of women was negligible compared to men and so data for both genders was pooled together in the analysis.

Information about musculoskeletal problems and exposure to WBV, posture and MMH, was obtained using a previously developed questionnaire [11], which had the questions grouped in four sections: A—general information, B—work satisfaction, C—work environment, D—musculoskeletal health information. The questions concerning general information sought details about physical characteristics, exercise habit, smoking and alcohol consumption, school years and number of jobs held as factors that could confound the true effect of the three variables selected for investigation. The questions concerning musculoskeletal health sought details on type of trouble experienced, number and typical duration of episodes, time off work and pain intensity consequences. Presence or absence of current LBP—pain and/or symptoms in the past 7 days and previous LBP—pain and or/symptoms in the past 12 months, were of principal interest, but information about other health problems and specific medical conditions, which had been treated, was also included in the questionnaire. The questions regarding WBV were in terms of driving experience (years of driving and daily driving hours), surface and environment of driving, style of driving and discomfort from different modes of vibration. Those regarding posture were in terms of five different possible configurations of the torso (torso against backrest, torso straight, torso bent, torso twisted, and torso twisted and bent simultaneously) and three possible frequencies of occurrence (never, occasionally, and often). MMH was assessed in terms of the weight of load (light load <5 kg, medium load 5–10 kg, heavy load >10 kg) and frequency (self-reported) in a typical workday, for lifting and pushing, whether lifting was done in awkward postures (bent or twisted torso) and whether lifting was done immediately after driving (sometime, often).

Table 1
Questionnaire distribution and response rate for the driver groups and overall

Study group	Source of volunteers	Number sent	Number returned	Number in analyses	Response rate (%)
Police drivers	Police	75	60	58	77.3
Tractor drivers	City councils	30	25	23	
	Commercial farms	15	12	10	
	Small-scale farm	40	28	27	
	Total	85	65	60	70.6
Truck/van drivers	City councils	30	25	24	
	Haulage company	50	24	21	
	Printing press	10	6	5	
	Independent	20	15	14	
	Total	110	70	64	58.2
Pilots	Helicopter companies	80	67	62	77.5
Bus drivers	City bus company	80	68	61	76.3
Construction (Works) drivers					
	Quarries	30	25	25	
	Roads/building sites	40	15	15	
	Total	70	34	34	48.6
Taxi drivers	Taxi	90	30	30	33.3
Controls	University	40	28	28	
	Haulage company	30	17	11	
	Staff nurse	10	5	5	
	Off-shore workers	10	5	5	
	City councils	10	4	0	
	Total	100	59	49	49.0
	Grand totals	690	453	418	60.6

Vibration (WBV) measurements in the three orthogonal axes (x-fore and-aft, y-lateral and z-vertical) were performed on a sample of the vehicles used by the volunteers during their work (tractor drivers—4, truck/van drivers—4, bus drivers—5, works drivers—6, taxi drivers—3, pilots—2). The measurements were done during actual work tasks and according to the recommendations of the ISO 2631 (1997) standard [12], at the driver/seat interface using a tri-axial seat pad accelerometer (Liberty Mutual whole-body vibration meter 2.0). The accelerometer was placed on the seat below the driver's ischial tuberosities when sitting and connected to a portable field computer packaged in a rugged instrument case. For each set of measurements, the case was securely positioned within the cabin of the vehicle and the recorded accelerations were acquired over a 5-min period. For each vehicle type, vector sum of the root mean square (rms) of frequency weighted accelerations, **a**, was calculated according to the following formula:

$$\mathbf{a} = [(1.4\mathbf{a}_x)^2 + (1.4\mathbf{a}_y)^2 + \mathbf{a}_z^2]^{0.5}(\mathrm{m\,s^{-2}}).$$

Based on the questionnaire responses (posture and MMH) and the direct WBV measurements, aggregate measures for WBV exposure (total vibration dose, TVD), posture exposure (posture score, PS) and MMH exposure (MMH score) were computed for each volunteer (described in Appendix A). Van der Beek et al. [13] identified the need for aggregate measures of exposure in epidemiological investigations and describes an approach to aggregate various force measures into integrated external exposure measures, though this was with respect to pushing and pulling. They also differentiate between external (occurring outside the body) and internal (biomechanical loads and stressed induced on the body) exposure. TVD of the present work, is defined after cumulative vibration dose of Bovenzi et al. [14]. PS, is defined after their aggregate posture stress measure, though with severity points imposed on each identified posture configuration. This was done to reflect suggestions in the literature that stress from sitting posture is minimal when the torso is leant (supported) against a back support, in neutral upright position, and increased as the position adopted increases in complexity [15,16]. Manual handling score (MHS), the aggregate measure for MMH exposure is peculiar to the present work. It differs from other MMH aggregate exposure measures found in the literature, in that it gives consideration to many of the aspects of MMH, and attempt is made to tie together external and internal exposure by allocating stress severity points that reflect the relative spinal loadings due to the different aspects [17–21]. Low, medium and high levels of the measures are defined as follows:

Total VD: 0–8.5, 8.6–15.0, >15.0
PS: 0–6.0, 7–12.0, >12.0
MMH score: 0–8, 9–16, >16

While cumulative vibration dose has been validated and widely applied in other studies, the penalty/severity points of PS and MMH score are yet to be validated for representative ness and wider application.

Statistical analyses were carried out using SPSS 11.5. Group differences in the continuous variables were analysed by Student's *t*-test. Association between presence of LBP (current and previous) and several independent occupational and personal factors was assessed by fitting univariate binary logistic–binomial regression models. For the aggregate exposure factors, Odds ratios (OR) and 95% confidence intervals (95% CI) were obtained with appropriate adjustment for potential confounding occupational and personal factors. Log linear backward elimination analysis was performed to define best models for presence of LBP and the exposure scores (TVD, PS and MHs). In all tests, $p<0.05$ was accepted as the minimum for significance.

3. Results

3.1. Questionnaire distribution and characteristics of study groups

Table 2 presents the personal characteristics summarised data for the respondents (including the aggregate exposure measures) according to study group.

A total of 690 copies of the study questionnaire were sent out for completion and 453 copies were returned (Table 1). Thirty-five questionnaires were subsequently excluded because they did not meet the inclusion criteria or had more than half of the questions left unanswered. Thus, the overall response rate (for those included in final analysis) was 60.6%. As can be seen from Table 1, the response rates varied between the

Table 2
The summarised data for personal characteristics (including the aggregate exposure measures) of the respondents according to study group, i.e., mean and (standard deviation)

Variable	Study group							
	Police ($N=58$)	Tractor ($N=60$)	Truck/van ($N=64$)	Pilots ($N=62$)	Bus ($N=61$)	Works ($N=34$)	Taxi ($N=30$)	Control ($N=49$)
Age*	34.5 (5.90)	45.4 (15.17)	46.9 (10.98)	50.0 (8.31)	47.6 (10.41)	48.7 (10.49)	49.3 (8.33)	40.0 (8.38)
Height (cm)*	178.6 (6.74)	177.7 (6.78)	176.4 (6.67)	178.0 (6.83)	172.9 (8.45)	175.6 (6.35)	176.4 (7.40)	175.2 (7.86)
Weight (kg)	83.1 (11.37)	83.8 (12.49)	85.9 (14.78)	82.2 (8.26)	84.9 (15.72)	85.4 (13.68)	88.5 (18.48)	79.7 (14.09)
BMI (kg/m^2)*	26.0 (2.74)	26.5 (3.90)	27.7 (4.49)	26.0 (2.01)	28.3 (4.36)	27.8 (4.46)	28.3 (4.77)	25.9 (3.62)
Schooling (years)*	12.5 (2.39)	11.5 (2.40)	10.7 (2.48)	13.0 (1.96)	11.8 (2.33)	11.1 (1.60)	11.2 (1.57)	14.3 (3.44)
Tobacco quantity (sticks/day)*	13.9 (5.62)	18.6 (11.66)	17.6 (9.04)	16.9 (9.85)	23.6 (11.41)	27.3 (11.66)	27.5 (13.31)	16.8 (10.03)
Work satisfaction *	57.5 (9.73)	56.5 (9.41)	52.6 (11.65)	59.2 (7.49)	54.6 (9.73)	50.6 (10.85)	52.6 (12.22)	55.9 (10.41)
Current job (years)*	12.9 (7.24)	13.9 (12.40)	10.5 (8.57)	17.8 (9.77)	16.1 (11.69)	12.4 (10.45)	11.1 (8.69)	8.6 (8.12)
Total vibration dose (years m^2 s^{-4})*	5.2 (3.34)	12.4 (11.33)	2.2 (2.25)	17.7 (10.75)	7.2 (5.22)	10.4 (8.97)	5.0 (3.83)	0.0
Posture score*	6.2 (3.91)	13.9 (6.91)	9.7 (6.42)	8.2 (3.58)	8.2 (5.32)	11.6 (6.42)	5.8 (3.63)	10.7 (4.51)
MMH score*	4.2 (5.21)	8.6 (5.23)	8.8 (5.52)	2.6 (4.36)	1.3 (3.41)	6.3 (6.75)	7.4 (4.66)	3.5 (5.27)

*Significant ($p<0.05$).

groups. They were particularly low for taxi drivers (33.3%) and works drivers (48.6%) but quite high for pilots and police drivers (77.5% and 77.3% respectively), bus drivers (76.3%) and tractor drivers (70.6%).

The groups differed significantly in their personal characteristics but one, i.e., weight (Table 2).

- Police drivers were significantly younger than the other groups, controls younger than pilots, truck/van drivers and bus drivers.
- Bus drivers were significantly shorter than police drivers, tractor drivers and pilots and associated with significantly higher BMI values than police drivers, controls and pilots.
- Pilots associated with significantly higher work satisfaction scores than truck/van drivers, works drivers and taxi drivers, and police drivers with higher scores than works drivers.
- Schooling was significantly higher for controls than taxi drivers, works drivers, tractor drivers, police drivers and bus drivers, significantly higher for pilots than truck/van drivers, taxi, drivers, works drivers and tractor drivers but not bus and police drivers, and significantly higher for police drivers than truck/van drivers.
- Police drivers showed to consume significantly less tobacco than works drivers and taxi drivers, and taxi drivers showed to consume significantly more tobacco than truck/van drivers and pilots.
- Years in current job was significantly higher for pilots than truck/van drivers, taxi drivers and controls, and significantly higher for bus drivers than truck/van drivers and controls.

Concerning the WBV, posture and MMH exposures (Table 2):

- Pilots had significantly higher TVD values than the other groups, tractor drivers higher vibration dose values than police drivers, truck/van drivers, bus drivers and taxi drivers, and works drivers had higher vibration dose values than police drivers, truck/van drivers and taxi drivers. The differences between police drivers, truck/van drivers and taxi drivers did not reach significance level, nor did the differences between tractor drivers and works drivers.
- Tractor drivers had significantly higher PS values than other groups except works drivers, works drivers had higher score values than police drivers and taxi drivers, and controls had higher score values than police drivers. The PS values for police drivers, pilots, bus and taxi drivers did not show to differ significantly nor did the score values for tractor drivers and works drivers.
- The MMH score values for tractor drivers and truck/van drivers were significantly higher than the score values for pilots, bus drivers, controls and police drivers, and the score values for taxi drivers were higher than the score values for controls, bus drivers and pilots. The differences between tractor drivers, truck/van drivers, works drivers and taxi drivers did not reach significance level, nor did the differences between bus drivers, police drivers, pilots and controls.

3.2. LBP and the risk factors

One hundred and thirty-three persons (55.7%) reported previous LBP (pain in past 12 months), in which regards, pilots associated with the highest prevalence (80.6% reporting), tractor drivers (43.3%) with lowest prevalence and prevalence for the other groups ranged from 44.1% (works drivers) to 63.3% (taxi drivers) (Fig. 1). One hundred and twenty-six persons (30.1%) reported current LBP (pain in last 7 days), in which regards, taxi drivers associated with highest prevalence (44.1%), though prevalence for pilots was only slightly lower (41.9%). Tractor drivers associated with the lowest prevalence (16.7%) and the prevalence for the other groups ranged from 19.0% (police drivers) to 36.7% (controls).

3.2.1. Relationship with confounding and occupational factors

Tables 3–5 present the unadjusted OR and 95% CI for association of independent confounding and occupational risk factors with LBP (previous and current).

Confounding factors (Table 3): Noticeable excesses of previous LBP were found for study group, i.e., pilots relative to controls (OR 3.125, 95% CI 1.340–7.288), current consumption of tobacco (OR 1.927, 95% CI

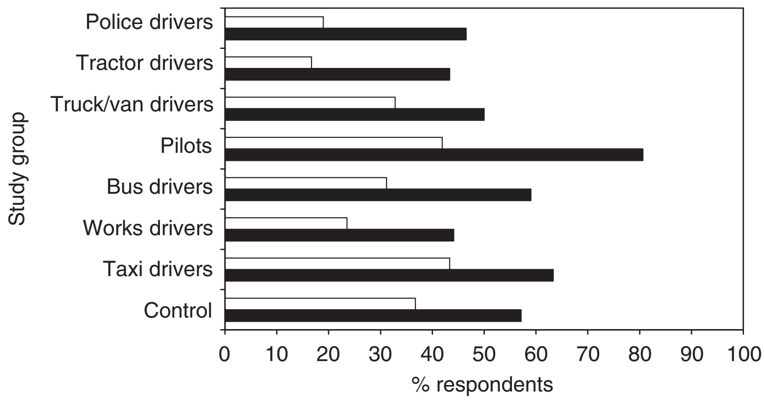

Fig. 1. The summarised data for prevalence of LBP: □, current LBP (7 days); ■, previous LBP (12 months).

1.073–3.450) and past LBP, i.e., >12 months prior to study (OR 4.099, 95% CI 2.476–6.786). Noticeable excesses of current LBP were found for other job (OR 2.438, 95% CI 1.064–5.549) and past LBP (OR 2.963, 95% CI 1.854–4.734).

Occupational factors (Tables 4 and 5): For both previous and current LBP, discomfort was generally associated with the highest OR and best defined 95% CI. Noticeable excesses of previous LBP were also found for all the posture factors except one 'seat condition' factor (seat is adjustable) and one 'posture configuration' factor (torso straight); for only one MMH factor (lifts loads awkwardly—postures) and for all the vibration factors except two, i.e., uses suspension seat and type of suspension seat.

Noticeable excesses of current LBP were found for three of the posture factors, i.e., two 'seat condition' factors (seat has poor backrest and uses auxiliary backrest) and one 'posture configuration' factor (torso twisted); for two of the vibration factors, i.e., seat bottoms out and driving style.

It can be seen from Table 4 that the OR for the vibration related factors were considerably increased (between 1.670 and 3.525). The OR for the posture factors were also considerably increased, i.e., between 1.755 and 2.644, and the 95% confidence intervals generally better defined than those for the seat condition factors (Table 5). Furthermore, an increased OR was determined for lifts loads awkwardly.

3.2.2. Relationship with aggregate exposure measures

In this stage of analysis, TVD, PS, MHS were used in binary logistics regression analyses firstly, as categorical variables and then as continuous variables. In both cases, age, current consumption of tobacco and other job were entered into the model as confounding variables, age because it has often been reported in previous works; current consumption of tobacco and other job because in the crude univariate analyses of risk, the two variables were found to associate significantly with previous and/or current LBP. Results from the analyses are presented in Tables 6 and 7.

Previous LBP: When the three exposure scores were imputed as categorical variables (Table 6), excesses of LBP risk (increased OR (Exp *B*)) were found for TVD and PS (the medium and high categories) as well as for MHS (medium category) though none of the OR showed to be statistically significant as did none of the OR for the included confounding factors. Significant linear dose response trends were however, suggested for the three exposure scores ($p<0.05$). On the other hand, imputing the exposure scores as continuous variables (Table 7), produced excesses of LBP risk for total vibration dose (not statistically significant) and PS (statistically significant). A significantly decreased OR was also found for current consumption of tobacco.

Current LBP: Imputing the exposure scores as categorical variables (Table 6), produced excesses of LBP risk (increased OR (Exp *B*)) for TVD (the high category), for PS (intermediate and high categories) and for MHS (intermediate category), though none of the OR showed statistical significance as did none of the included confounding factors. Significant linear dose response trends were however suggested for PS and MHS, but not TVD. On the other hand, imputing the exposure scores as continuous variables (Table 7), produced excess of LBP risk for only PS which showed to be statistically significant, and none of the included confounding factors showed a significant association with current LBP.

Table 3
Unadjusted univariate OR and 95% CI for association of confounding risk factors with previous (12 months) LBP and current (7 days) LBP

Variable	Previous LBP			Current LBP		
	N (%)	OR	95% CI	*N* (%)	OR	95% CI
Study group						
Control	28 (57.1)			18 (36.7)		
Police	27 (46.6)	0.653	0.304–1.405	11 (19.0)	0.403	0.168–0.968
Tractor	26 (43.3)	0.574	0.268–1.229	10 (16.7)	0.344	0.141–0.842
Truck	32 (50.0)	0.750	0.355–1.585	21 (32.8)	0.841	0.385–1.836
Pilot	50 (80.6)	3.125	1.340–7.288	26 (41.9)	1.244	0.576–2.684
Bus	36 (59.0)	1.080	0.504–2.314	19 (31.1)	0.779	0.352–1.724
Works	15 (44.1)	0.592	0.245–1.431	8 (23.8)	0.530	0.198–1.415
Taxi	19 (63.3)	1.295	0.509–3.295	13 (43.3)	1.317	0.521–3.327
Sex						
Male	222 (57.1)			118 (29.3)		
Female	11 (77.3)	2.242	0.702–7.160	8 (53.3)	2.760	0.979–7.785
Age						
0.0–25.0	8 (50.0)			4 (25.0)		
26.0–45.0	103 (53.4)	1.144	0.413–3.174	52 (26.7)	1.106	0.342–3584
>45.0	112 (58.4)	1.402	0.507–3.880	70 (33.5)	1.511	0.470–4.855
BMI						
0.0–24.9	67 (58.3)			33 (28.7)		
25.0–29.9	108 (57.8)	0.979	0.612–1.568	60 (32.1)	1.174	0.707–1.950
>29.9	38 (56.7)	0.939	0.511–1.726	21 (31.3)	1.134	0.589–2.185
Schooling						
0–10	53 (49.1)			29 (26.8)		
11–15	98 (51.3)	1.094	0.682–1.753	49 (25.7)	0.940	0.550–1.606
<15	20 (52.6)	1.153	0.550–2.417	15 (39.5)	1.777	0.817–3.885
Exercises						
No	76 (53.5)			44 (31.0)		
Yes	157 (57.3)	1.165	0.775–1.752	82 (29.9)	0.951	0.613–1.477
Tobacco P						
No	120 (53.3)			67 (29.8)		
Yes	113 (59.2)	1.268	0.859–1.872	59 (30.9)	1.054	0.693–1.603
Tobacco C						
No	69 (66.3)			33 (31.7)		
Yes	44 (50.6)	1.927	1.073–3.450	26 (29.9)	1.090	0.588–2.022
Alcohol						
No	28 (56.0)			15 (30.0)		
Yes	205 (56.2)	1.007	0.555–1.826	111 (30.4)	1.020	0.535–1.943
Other job						
No	215 (54.8)			114 (29.1)		
Yes	18 (75.0)	2.470	0.960–6.355	12 (50.0)	2.438	1.064–5.549
Past LBP						
No	111 (46.1)			57 (23.7)		
Yes	91 (77.8)	4.099	2.476–6.786	56 (47.9)	2.963	1.854–4.734

Key: Tobacco P–past consumption of tobacco (smoke or chew); Tobacco C–current consumption of tobacco (smoke or chew).

The log linear analysis (Table 8) found a best model for previous LBP, that included one main effect variable and two interaction effect variables, i.e., previous LBP; the two-way interaction TVD × PS; the two-way interaction PS × MHS. The *p*-values for the variables suggest that of the three variables, the

Table 4
Unadjusted univariate OR and 95% CI for association of vibration related factors with previous (12 months) LBP and current (7 days) LBP

Variable	Previous LBP				Current LBP	
	N (%)	OR	95% CI	*N* (%)	OR	95% CI
Discomfort from vibration						
Vertical						
No	91 (41.0)			40 (18.0)		
Yes	108 (79.4)	5.553	3.387–9.102	64 (47.1)	4.044	2.502–6.537
Fore-aft						
No	137 (48.9)			65 (23.2)		
Yes	54 (77.1)	3.523	1.924–6.452	34 (48.6)	3.124	1.812–5.386
Lateral						
No	128 (48.7)			58 (22.1)		
Yes	67 (72.8)	2.827	1.682–4.750	44 (47.8)	3.240	1.961–5.354
Shock/jerking						
No	119 (49.2)			61 (25.2)		
Yes	80 (70.8)	2.506	1.554–4.033	44 (38.9)	1.892	1.175–3.043
Uplift from seat						
Never	75 (47.5)			40 (25.3)		
<5 times	80 (60.2)	1.670	1.047–2.664	41 (30.8)	1.315	0.786–2.198
$>5, <5$/h	27 (65.9)	2.134	1.042–4.372	10 (24.4)	0.952	0.428–2.113
>5/h	19 (57.6)	1.502	0.704–3.204	14 (42.4)	2.174	0.999–4.732
Seat bottoms out						
Never	77 (44.8)			39 (22.7)		
<5 times	89 (67.4)	2.554	1.593–4.094	45 (34.1)	1.764	1.063–2.928
$>5, <5$/h	20 (55.6)	1.542	0.749–3.177	11 (30.6)	1.501	0.678–3.319
>5/h	14 (66.7)	2.468	0.949–6.417	9 (42.9)	2.558	1.004–6.515
Seat suspension						
No	41 (42.7)			21 (21.9)		
Yes	108 (53.7)	1.558	0.954–2.544	59 (29.4)	1.484	0.838–2.627
Types of seat suspension						
Mechanical	35 (56.5)			18 (29.0)		
Air	53 (53.0)	0.870	0.460–1.645	28 (28.0)	0.951	0.472–1.916
Hydraulic	9 (52.9)	0.868	0.296–2.547	5 (29.4)	1.019	0.313–3.310
Combination	11 (52.4)	0.849	0.314–2.290	7 (33.3)	1.222	0.423–3.528
Driving style						
Smooth						
No	55 (56.1)			31 (31.6)		
Yes	98 (48.0)	1.213	0.604–2.436	51 (25.0)	0.947	0.471–1.903
Slow						
No	125 (50.4)			68 (27.4)		
Yes	28 (51.9)	1.217	0.580–2.553	14 (25.9)	0.906	0.418–1.966
Fast						
No	128 (48.3)			70 (26.4)		
Yes	25 (67.6)	2.439	1.093–5.445	12 (32.4)	1.302	0.593–2.859
Accel/brake						
No	109 (46.8)			55 (23.6)		
Yes	44 (63.8)	2.204	1.145–4.242	27 (39.1)	2.027	1.060–3.876
Vehicle gearing						
Automatic	40 (46.0)			25 (28.7)		
Mechanical	91 (48.9)	1.126	0.767–1.875	47 (25.3)	0.839	0.474–1.483
Both	21 (75.0)	3.525	1.358–9.148	8 (28.6)	0.992	0.387–2.545

Table 5
Unadjusted univariate OR and 95% CI for association of posture and MMH related factors with previous (12 months) LBP and current (7 days) LBP

Variable	Previous LBP			Current LBP		
	N (%)	OR	95% CI	*N* (%)	OR	95% CI
Posture related factors						
Discomfort						
No	126 (45.3)			60 (21.6)		
Yes	102 (78.5)	4.395	2.719–7.104	63 (48.5)	3.416	2.185–5.343
Seat is adjustable						
No	4 (50.0)			3 (37.5)		
Yes	226 (55.8)	1.203	0.311–5.118	121 (29.9)	0.710	0.167–3.018
Adjusts seat						
No	18 (40.0)			10 (22.2)		
Yes	203 (58.0)	2.071	1.100–3.901	110 (31.4)	1.604	0.767–3.356
Good back rest						
No	64 (71.9)	2.420	1.450–24.036	39 (43.8)	2.182	1.341–3.552
Yes	164 (51.4)			84 (26.3)		
Use aux back rest						
No	173 (52.9)			88 (26.9)		
Yes	27 (93.1)	12.017	2.811–51.367	18 (62.1)	4.444	2.019–9.782
Twisted no vib						
No	159 (53.0)			88 (29.3)		
Yes	38 (74.5)	2.592	1.327–5.062	17 (33.3)	1.205	0.640–2.269
Torso on back rest						
No	21 (38.9)			12 (22.2)		
Yes	208 (58.5)	2.219	1.235–3.988	111 (31.1)	1.579	0.800–3.116
Torso straight						
No	35 (55.6)			19 (30.2)		
Yes	111 (48.1)	0.740	0.423–1.285	62 (26.8)	0.850	0.461–1.566
Torso bent						
No	57 (44.9)			31 (24.4)		
Yes	162 (60.2)	1.871	1.221–2.865	89 (33.1)	1.523	0.944–2.455
Torso twisted						
No	85 (44.0)			43 (22.3)		
Yes	129 (67.5)	2.644	1.745–4.005	73 (38.2)	2.158	1.380–3.376
Twisted and bent						
No	83 (45.9)			47 (26.0)		
Yes	55 (59.8)	1.755	1.055–2.920	31 (33.7)	1.449	0.840–2.499
MMH related factors						
Lifts						
<5 kg						
No	188 (56.1)			99 (29.6)		
Yes	38 (55.1)	0.920	0.490–1.727	24 (34.8)	1.892	0.950–3.768
Lifts						
5–10 kg						
No	185 (57.1)			100 (30.9)		
Yes	40 (51.9)	0.675	0.363–1.257	23 (29.9)	1.122	0.563–2.235
Lifts						
>10 kg						
No	168 (56.6)			96 (32.3)		
Yes	56 (53.3)	0.763	0.405–1.440	26 (24.8)	0.922	0.458–1.856
Awkwardly						
No	45 (48.9)			20 (21.7)		
Yes	59 (63.4)	2.004	1.085–3.702	30 (32.3)	1.786	0.895–3.564
After drive						
No	30 (50.0)			18 (30.0)		
Yes	90 (57.3)	1.110	0.482–2.512	43 (27.4)	1.099	0.434–2.778

Table 5 (*continued*)

Variable	Previous LBP			Current LBP		
	N (%)	OR	95% CI	*N* (%)	OR	95% CI
Pushes						
< 5 kg						
No	228 (55.9)			122 (29.9)		
Yes	4 (44.4)	0.684	0.165–2.847	3 (33.3)	1.459	0.321–6.645
Pushes						
5–10 kg						
No	222 (55.9)			120 (30.2)		
Yes	10 (50.0)	0.865	0.330–2.268	5 (25.0)	0.723	0.238–2.194
Pushes						
> 10 kg						
No	197 (55.8)			108 (30.6)		
Yes	35 (54.7)	0.981	0.571–1.645	17 (26.6)	0.820	0.448–1.501

Table 6
Binary logistics regression model for risk of previous (12 months) LBP and current (7 days) LBP with total vibration dose, posture score and MMH score imputed as categorical variables and adjusted for age, current smoking habit and other job as cofounders (measure of association = OR, i.e., Exp (*B*) and associated 95% CI)

Variable	Previous LBP		Current LBP	
	Exp (*B*)	95% CI for Exp (B)	Exp (*B*)	95% CI for Exp (B)
Total vibration dose (yr $m^2 s^{-4}$)		p for trend = 0.037		
0.0–8.5 ($N = 124$)				
8.6–15.0 ($N = 32$)	1.297	0.547–3.075	0.888	0.356–2.220
> 15.0 ($N = 33$)	1.519	0.589–3.928	1.313	0.534–3.230
Posture score		p for trend = 0.013		p for trend = 0.041
0–6 ($N = 77$)				
7–12 ($N = 66$)	2.003	0.963–4.165	1.288	0.598–2.777
> 12 ($N = 46$)	2.044	0.912–4.584	1.946	0.864–4.385
MMH score		p for trend = 0.043		p for trend = 0.040
0–8 ($N = 171$)				
9–16 ($N = 14$)	3.653	0.916–14.576	1.691	0.522–5.478
> 16 ($N = 4$)	0.807	0.104–6.232	0.805	0.077–8.460
Age				
0.0–45.0 ($N = 78$)				
> 45.0 ($N = 112$)	1.425	0.719–2.824	1.423	0.695–2.916
Tobacco C				
No ($N = 103$)				
Yes ($N = 86$)	0.510	0.271–0.962	0.912	0.473–1.758
Other job				
No ($N = 175$)				
Yes ($N = 14$)	2.792	0.708–11.016	2.443	0.790–7.549

Tobacco C—current consumption of tobacco (smoke or chew).

posture × manual handling interaction is the most important contributor and previous LBP the least important. A best model for current LBP was found that included two interaction variables, i.e., the three-way interaction PS × MHS × current LBP; the two-way interaction TVD × PS. The p-values for the two variables suggest that they made equal relative contribution. The final goodness of fit χ^2 was not significant for both

Table 7
Binary logistics regression model for risk of previous (12 months) LBP and current (7 days) LBP with total vibration dose, posture score and MMH score imputed as continuous variables and adjusted for age, current smoking habit and other job as cofounders (measure of association = OR, i.e., Exp (*B*) and associated 95% CI)

Variable	Previous LBP		Current LBP	
	Exp (*B*)	95% CI for Exp (*B*)	Exp (*B*)	95% CI for Exp (*B*)
Total vibration dose (yr $m^2 s^{-4}$)	1.007	0.970–1.046	0.990	0.954–1.027
Posture score	1.094	1.028–1.164	1.073	1.010–1.139
MMH score	0.970	0.915–1.029	0.953	0.896–1.014
Age				
0.0–45.0 ($N = 78$)				
>45.0 ($N = 112$)	1.511	0.769–2.971	1.632	0.798–3.338
Tobacco C				
No ($N = 103$)				
Yes ($N = 86$)	0.479	0.254–0.904	0.876	0.453–1.695
Other job				
No ($N = 175$)				
Yes ($N = 14$)	3.030	0.777–11.815	2.439	0.791–7.526

Tobacco C–current consumption of tobacco (smoke or chew).

Table 8
The summarised results of log linear analysis

Dependent variable	Iteration steps	Variables in model	DF	*p*	Goodness of fit (*p*-final)
Previous LBP (12 months)	10	TVD × PS	4	0.0043	0.177
		PS × MHS	4	0.0004	
		Previous LBP	1	0.0322	
Current LBP (7 days)	7	PS × MHS × Current LBP	4	0.0042	0.918
		TVD × PS	4	0.0043	

For both models, the iterative proportional fit algorithm converged at iteration 0.
The maximum difference between observed and fitted marginal totals is 0.000 and the convergence criterion is 0.250.
Key: DF = degrees of freedom; TVD = total vibration dose; PS = posture score; MHS = manual handling score.

previous LBP and current LBP models, i.e., $p > 0.05$, which indicates that there is good fit between the models and the data.

4. Discussion

This work represents another attempt to assess quantitatively the independent effects of vibration exposure, postural demands and MMH, as well as their combined effects, as risk factors for LBP among professional drivers. Other studies had been concerned with the effects of vibration alone and vibration and posture [22,23] or had evaluated relative role of the independent exposures in terms of population attributable fractions [24,25]. The data here indicate that differences existed between the driver and pilot groups in their occupational exposures to WBV, posture and MMH. They highlight how WBV, posture and MMH might contribute to precipitate LBP.

4.1. *Questionnaire distribution*

Between 33.3% (taxi drivers) and 77.5% (pilots) of the sent out copies were returned (Table 1), but for most of the groups, it was not certain whether these had come from persons who had been selected randomly since none of the researchers could be present to effect the randomisation and distribution of the questionnaires.

This had to be left to the discretion of a link person (particularly with respect to large organisations, which contributed their driving staff as volunteers). Moreover, an analysis of the non-responders, to establish that the sample of responding volunteers was representative of the total group of volunteers, could only be conducted for one group (bus drivers). Firstly, non-responders often refused further participation after initial contact or failed to respond to subsequent correspondences from the researchers and secondly, very limited time was granted for the study within large organisations, which often precluded contact with the non-volunteered persons.

Volunteers for the bus drivers group were chosen, according to the company off-duty schedule, i.e., between 11:00 a.m. and 12:00 p.m. on four randomly selected normal workdays (done in consultation with the personnel manager) and based on the proportions of male and females. The sample of bus drivers, closely approximate the entire driver population, in that, just over 97% of the driver population were men compared to 95% in the study sample. Considering, however, that the number of taxi drivers and works drivers in the study sample was very low and that an appreciable number of self-volunteered truck/van drivers were included, the data collected, particularly that relating to prevalence of LBP may not be representative of the wider population.

4.2. Assessment of the risk exposures

In assessing the exposures to WBV, posture and MMH, comparison between the groups regarding the individual aspects of the three factors revealed no clear trends. As such, aggregate exposure measures, which included all or some of the individual aspects, were computed. It was on these measures that risk assessment and categorisation of the driver groups was based.

TVD: Bovenzi et al. [14], define two measures, equivalent vibration magnitude and cumulative vibration dose, based on sum of measured 3-D weighted acceleration and duration of exposure. The values of cumulative vibration dose were computed using durations of exposure (daily in driving hours and total in full-time driving years), which were estimated from company records. Boshuizen et al. [1] defined TVD and used durations of exposure reported by subjects in a questionnaire survey to compute the values. The procedures for computing cumulative vibration dose have been applied in other related studies, and this suggested they are widely accepted as valid for aggregating WBV exposure. TVD of the present work is defined after cumulative vibration dose and the values were computed using questionnaire reported durations of exposure.

PS: In their evaluation of postural load among ports machinery operators, Bovenzi et al. [14], constructed a cumulative measure (perceived postural load) based on subjects' rating of frequency and/or duration of specific postures on a four-item scale (1–4 to i.e., seldom, sometimes, often, very often) during interview. The authors justified their approach, first, on the fact that individuals with musculoskeletal disorders did not tend to overestimate their physical workload when questionnaire data were compared with systematic observation; secondly on the fact that ergonomics investigations have shown a good agreement between self-reported and observed frequency, duration and magnitude of physical demands. For the present work, PS, the aggregate measure of posture exposure, is similarly based on specific posture configurations and subjects' reported frequencies of occurrence. Since severity score values were imposed on the different posture configurations, which reflected the differences in associated postural stress, the measure involves greater objectivity than does the measure of Bovenzi et al. However, the severity score values here were arbitrarily chosen, as such, the true states of postural stress may not have been well represented.

MHS: Damkot et al. [26] derived an aggregate measure for pushing tasks by multiplying weight of object (intensity) by the number of exertions made per day (frequency). Van Wendel de Joode et al. [27] defined aggregate scores for different tasks based on a rating scheme. The duration of awkward postures and magnitude of exerted forces in a task were compared with existing guidelines to obtain 'exceedance' fractions and the fractions for back posture, arm posture and forceful exertions were then added to arrive at the final score that reflected the total physical load for the task. For the present work, MHS, the aggregate measure of MMH exposure, is defined to reflect overall physical stress from key tasks (lifting and pushing/pulling) and risk factors in terms of intensity, frequency and duration. Severity score values were chosen for the tasks and effect scores for the risk factors, according to the patterns of induced spinal loading suggested in the literature. Schibye et al. [20] for example found compression forces at L4/L5 ranged between 540 and 610 N and between

Table 9
Exposure and risk characteristics of the groups based on the aggregate exposure measures

Study group	Measures of exposure			Category of risk[a]
	Total vibration dose	Posture score	Manual handling score	
Tractor drivers	High	High	High	1
Police drivers	Medium	Low	Medium	3
Truck/van drivers	Low	Medium	High	2
Pilots	High	Medium	Low	2
Bus drivers	Medium	Medium	Low	3
Works drivers	High	High	Medium	1
Taxi drivers	Medium	Low	High	2

[a] 1—High; 2—Medium; 3—Low.

930 and 1380 N during pushing and pulling respectively of 25 kg wheeled containers; the compression forces averaged 4195 and 1117 N respectively during lifting and carrying of 25 kg bins. Similarly, Granata et al. [19] found that spinal load increased significantly with box weight and asymmetry of posture but not frequency of lifting. It is therefore considered that, MHS score is a more encompassing and objective measure of exposure than the van Wendel de Joode et al. measure. However, since the severity score and effect score values were chosen for convenience the true states of exposure may not have been well represented.

The computed values of aggregate exposure, suggested that tractor drivers and works drivers are high-risk groups (had high values for two or more of the three exposure measures). Taxi drivers, truck/van drivers, and pilots are medium risk groups (had high value for one or other of the exposure measures) and police drivers and bus drivers are low risk groups (medium and/or low values for the three exposure measures) (Table 9).

4.3. *Risk and relative role of the exposures*

Univariate binary logistics regression analyses showed that three factors of vibration exposure (uplifting from seat/seat bottoming out, driving style and vehicle gearing), associated significantly with prevalence of previous LBP (Table 4). All the factors of posture exposure but two (seat is adjustable and 'torso straight' posture) and one factor of MMH exposure (lifting in awkward posture), also associated significantly with prevalence of LBP (Table 5). Seat bottoming out and driving style (particularly accelerating/braking), good backrest, use auxiliary backrest and 'torso twisted' posture, also showed to associate significantly with current LBP. On the other hand, the aggregate exposure analysis (adjusted for confounding factors) showed, that PS alone associated significantly with prevalence of LBP (Tables 6 and 7).

These results point to a particular importance of posture exposure for precipitation of LBP, they also indicate that the importance of vibration exposure is in the shock/jerking events that occur. The finding that lifting and pushing of loads did not associate significantly with prevalence of LBP was a surprising result in that it contradicts the findings of most other studies [28,29]. However, as Xu et al. [30], have suggested, the results may be attributed to the fact that light loads were often handled by the groups surveyed here and/or that the work tasks generally required low physical effort.

The log linear model analyses here pointed to an importance of past LBP trauma for precipitation of previous and current LBP and indicated that the role of the three exposures (vibration, posture and MMH) is in two or more interaction effects of the independent exposures rather than due to the independent exposures on their own (Table 8). The findings are consistent with observations from previous works. Hartvisgen et al. [31], for example reported that sitting-while-working on its own correlated poorly with LBP, and Burdorf and Sorock [32] have reported that combination of prolonged static postures or frequent twisting of the spine and vibration exposure associated with LBP, sciatic and disc herniation more strongly than sedentary or dynamic physical work activity alone.

5. Conclusions

This study investigated the relative role of WBV, posture and manual materials handling as risk factors for LBP. In line with the stated aims, the following conclusions are made.

(a) Driver groups differ in their occupational exposures to WBV, posture and manual materials handling such that, those with high exposures in at least two of the factors can be classed as high-risk groups, those with high exposure in any one of the factors classed as medium-risk groups and those with only medium or low exposures classed as low-risk groups.
(b) Independent occupational factors related to posture exposure and vibration associate most consistently with prevalence of LBP, and the importance of vibration is in shock/jerking events that occur rather than regular sinusoidal events.
(c) 'Combined exposure' rather than the individual exposure to one of the three factors (WBV, posture, MMH) is the main contributor of the increased prevalence of LBP.

Acknowledgements

The authors would like to acknowledge the support provided by the Health and Safety Executive, UK and the Liberty Mutual Research Institute for Safety, Hopkinton, Massachusetts, USA.

Appendix A. Computational details for the aggregate exposure measures

PS were determined as follows:

Firstly, severity points were assigned to the postures and frequencies of occurrence, i.e.,

Postures: torso against backrest—1, torso straight—2, torso bent—3, torso twisted—4, torso bent and twisted simultaneously—5;

Frequencies: Never—0, occasionally—1, often—2.

Secondly, the products of posture severity point and frequency severity point were added across all identified postures.

MMH scores were determined as follows:

Firstly, severity points were assigned to tasks, load weight, awkward postures and drive, i.e.,

Tasks: Lifts loads—8; Pushes loads—6;
 Lifts in awkward posture—1; Lifts immediately after driving—1
Load weight (W): 0–5 kg—1.2/20 for both lifting and pushing
 5–10 kg–1.4/15 for both lifting and pushing
 >10 kg–1. 8/10 for both lifting and pushing
Awkwardness of posture (P): Bent—0.2; Twisted—0.1
Drive factor (O): Soon after—0.1

Secondly, effect scores were computed for the load, posture and drive factors, i.e.,

$$\text{Load effect score (LES)} = 8 + \sum(W_i \times f_i) \text{ or } 6 + \sum(W_i \times f_i)$$

which ever is of higher numerical value W_i is the severity point for the identified ith category of load, f_i the reported frequency of handling the ith category of load.

$$\text{Posture effect score (PES)} = 1 + \sum(P_i \times f_i)$$

Here P_i is the severity point for the identified ith awkward posture, f_i the frequency of the identified ith posture (occasionally—1, often—2)

$$\text{Drive factor effect score (DFES)} = 1 + 0.1 \times f.$$

Here f is the frequency of lifting after driving (occasionally—1, often—2).

Table B1

Vehicle/machine	$\mathbf{a}_x$ (m s^{-2})	$\mathbf{a}_y$ (m s^{-2})	$\mathbf{a}_z$ (m s^{-2})	$\mathbf{a}_i$ (m s^{-2})
Tractor	0.483	0.493	0.484	0.949
Harvester	0.216	0.220	0.386	0.531
Telescopic handler	0.561	0.505	0.649	1.104
ATV—Quad bike	0.368	0.394	0.641	0.904
Truck artic	0.132	0.181	0.235	0.354
Truck tipper	0.165	0.225	0.326	0.463
Tug-master truck	0.275	0.246	0.395	0.589
Van	0.255	0.245	0.346	0.543
Bus	0.247	0.321	0.478	0.677
Dumper	0.323	0.412	0.433	0.756
Loading shovel	0.537	0.543	0.436	1.003
Excavator	0.432	0.257	0.598	0.844
Pay loader	0.365	0.293	0.501	0.747
Bob cat	0.811	0.772	0.990	1.654
Fork lift truck	0.241	0.181	0.208	0.413
Garbage truck[a]	0.1	0.2	0.4	0.480
Helicopter	0.540	0.559	0.506	1.050

[a]Values were obtained from Internet resource—National Institute for Working Lift Database in Sweden, located at: http://umetech.niwi.se.

Thirdly the individual load, posture and drive scores were added together.

For vibration exposure, the vector sums of acceleration, together with the questionnaire information on duration of driving, i.e., exposure to WBV from various vehicles in current job expressed as work driving years, permitted estimation of a cumulative measure in terms of TVD (years m^2 s^{-4}). This was determined according to the energy equivalence principle using the 'second power' time dependency proposed by ISO 2631-1 for daily exposures [14] as follows:

$$\text{Total vibration dose} = \sum \mathbf{a}_i^2 t_i \ (\text{years}\,\text{m}^2\,\text{s}^{-4}),$$

where $\mathbf{a}_i$ is the estimated vector sum of weighted accelerations measured for vehicle i (Appendix B) and t_i is the time in years over which vehicle i was driven.

Appendix B

Representative root mean square (rms) of frequency weighted average accelerations ($\mathbf{a}_x$, $\mathbf{a}_y$, $\mathbf{a}_z$) and vector sum $\mathbf{a}_i$ values assigned to vehicles and machines used in the calculation of TVD dose (Table B1).

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