Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Sound and Vibration 284 (2005) 933–946
JOURNAL OF SOUND AND VIBRATION
www.elsevier.com/locate/jsvi

Whole body vibration and posture as risk factors for low back pain among forklift truck drivers

J. Hoy, N. Mubarak, S. Nelson, M. Sweerts de Landas, M. Magnusson, O. Okunribido*, M. Pope

Department of Occupational and Environmental Medicine, Liberty Safework Research Centre, University of Aberdeen, Foresterhill, Aberdeen AB25 2ZP, UK

Received 9 June 2003; received in revised form 31 March 2004; accepted 21 July 2004
Available online 13 December 2004

Abstract

A cross-sectional study was conducted to investigate the risks from whole-body vibration and posture demands for low back pain (LBP) among forklift truck (forklift) drivers. Using a validated questionnaire, information about health history was obtained over a period of two weeks in face-to-face interviews. The forklift drivers were observed in respect of their sitting posture, including frequency with which different positions were adopted (bending, leaning and twisting) and postural analyses were conducted using the OWAS and RULA techniques. Forklift vibrations at the seat (exposure) were measured in the three orthogonal axes (x-fore and aft, y-lateral and z-vertical) under actual working conditions according to the recommendations of ISO 2631-1. The results showed that LBP was more prevalent amongst forklift drivers than among non-drivers and driving postures in which the trunk is considerably twisted or bent forward associated with greatest risk. Furthermore, forklift drivers showed to be exposed to acceptable levels of vibration in the x- and y-directions (i.e., below the EU Physical Agents Directive on Vibration Exposure recommended action level—$0.5\,m/s^2$), but not in the z-direction. There were indications that whole-body vibration acts associatively with other factors (not independently) to precipitate LBP.

*Corresponding author. Tel.: +44 1224 558199; fax: +44 1224 662990.
E-mail address: o.okunribido@abdn.ac.uk (O. Okunribido).

0022-460X/$ - see front matter
doi:10.1016/j.jsv.2004.07.020

1. Introduction

The benefits of application and development of human factors and ergonomics principles in industry cannot be overemphasised. Indeed, a worker-friendly workplace can generate short-term advantages such as cost reduction and productivity improvement as well as long-term benefits from increased employee motivation and reduced staff turnover, reduced absence due to sickness and reduced insurance costs. In recent times, new legislation, such as the European Directive for control of exposure to whole-body vibration [1], have been introduced, which require employers to reduce to the lowest practical level the health and safety risks to workers. These tend to place a legal obligation on companies to giving more consideration to human factors in their management practices.

It has been estimated that there are about 90,000 forklift truck (forklift) drivers working in UK industries, whose working conditions may not be ideal [2]. Firstly, forklift drivers are typically subject to two types of debilitating whole-body vibration (WBV), i.e., shock loads (instantaneous non-cyclic forces acting over a very short period of time) and sinusoidal vibrations (cyclic forces acting over a range of frequencies, typically between 0.5 and 80 Hz), which, however, rarely occur independently. Shock loads tend to be generated during movement over areas of transition from one surface to another, during movement over or across potholes and uneven surfaces and when an obstacle is hit. In extreme cases they may cause the driver to be thrown from his or her seat due to the lack of damping provided on forklifts. On the other hand, sinusoidal vibrations tend to predominate during movement on relatively smooth roads and paths, i.e., including little or no elevations and/or ditches and can be considerably high in amplitude. The particular nature of their occurrence (frequency and amplitude) is however, a function of the travel speed, model of truck and/or specific nature of the road surface. Secondly, forklift drivers are exposed to postural stress in that, performance of tasks with the trucks, often require that poor postures (awkward sitting positions) are adopted for long periods at a single time.

Various studies have found positive associations between exposure to WBV and development of low back pain (LBP) among occupational drivers including forklift drivers with some reporting on the effects of shock loading to the spine [3–6]. These suggest that irrespective of type, the outcome of WBV is an increase in discomfort, pain and/or injury to the task operator, consequently leading to a marked reduction in performance. In the main, however, the role of vibration is yet not clear. Indeed, there are many confounding or contributing factors that influence the hazard to workers caused by exposure to WBV, which make the relationship between WBV and LBP a complex research problem. The situation is made more complex by the fact that alongside WBV, exposure to several other occupational risk factors often occurs in driving jobs [7–10]. Despite these limitations, postural stress from static work postures, particularly bending and twisting, and vibration are the common physical work factors that have been associated with increased risk of back pain for occupational drivers.

This study was conducted to investigate the risks from WBV and posture demands, for LBP among forklift truck drivers. There were three specific objectives, to investigate the prevalence of LBP, to evaluate the risks associated with different postures adopted by the drivers, to quantify the forklift driver's vibration exposure.

2. Subjects and methods

The study was a cross-sectional study, which involved two groups of workers (forklift drivers and controls). It was carried out within a paper mill in response to the company's request for an investigation to assess the risks for development of back pain amongst forklift drivers whose main duties were, off-loading finished products in production area, stacking/moving products in storage area, and loading products onto trucks. In these tasks, the forklifts were generally moved over three main types of surfaces, grainy tarmac, asphalt and concrete. Grainy tarmac constituted most of the bays and isles. Asphalt constituted majority of the surrounding main tracks and concrete was the constituent of a small but appreciable portion of the warehouse. While the drivers were full-time forklift operators working within the dispatch/storage department, the controls comprised workers from other departments within the same company, who did not at any time drive forklifts or other vehicles during their work. Effort was made to match the controls to the drivers on age, by imposing a maximum age difference of three years. Forty-six persons (23 drivers and 23 controls) agreed to participate in the study.

A previously developed and validated questionnaire [11] was used to obtain information about health history (particularly LBP, neck and shoulder pain), driving experience and sitting (driving) posture over a period of two weeks in face-to-face interviews. The questionnaire consists of four sections: general information, musculoskeletal health information, work environment information and job satisfaction. For the present work, the general information section included questions about anthropometry, smoking and exercise habit, educational level and other lifestyle factors that have been linked to risk of musculoskeletal ill-health. In assessing health problems, emphasis was on medical symptoms and pain intensity to the back, in the last 12 months. The work environment information section included questions about amount of driving, driving environment, as well as questions about the occupational risk factors of posture, and lifting. Job satisfaction was assessed in terms of psychosocial aspects of work (PAW). Fifteen statements were included to determine the attitudes towards three specific aspects: general job satisfaction, social support from colleagues/managers and the mental stress of work. Face-to-face interview was chosen over self-administration of the questionnaire as this allowed for collection of more complete and accurate data. Indeed, the face-to-face interview technique availed the interviewers opportunity to explain questions that were not readily understood by the respondents. However, due to time constraints, four persons were involved in conducting the interviews. Before conducting an interview, the participant was informed of the nature of the study and allowed to freely choose to participate.

The forklift drivers were observed and videotaped during their work in respect of their sitting posture, including frequency with which different positions were adopted (bending, leaning and twisting). From the video recordings, four frequently adopted postures were identified, and subjected to further investigation to determine the associated risks, using both Ovako working posture analysing system (OWAS) and rapid upper limb assessment (RULA) techniques [12,13]. One person did the posture assessments. The first posture (normal driving posture) was defined by forward bent trunk, left hand on the steering wheel and right hand on the truck controls, and often seen adopted during normal forward driving. The second posture (aligning forks posture) was defined by the trunk bent sideways and twisted with the neck twisted and often seen adopted when the forks were aligned in preparation for lifting a load. The third posture (reversing posture) was defined by considerably twisted trunk and neck and often seen adopted during reversing of the truck. The fourth posture (stowing posture) was defined by laterally bent trunk and extremely extended neck and often seen adopted during stowing of the paper rolls at high positions in the warehouse. OWAS seeks to identify postures, which put the body in positions where force exertions can be dangerous. In applying the technique, postures are recorded according to a coding system (as shown in Fig. 1), such that the code for a posture is a record of the posture itself (the first three cells), the load or force used (the fourth cell) and the stage in the cycle or task (the final two cells). The higher the code numbers, at any stage of the analysis, the further away from a desirable posture is the posture under consideration. Bases on the code numbers for each limb, an action category value is then determined. RULA, on the other hand, was developed to provide a rapid assessment of the loads on the musculoskeletal system of operators due to posture, muscle function and the forces exerted. It is designed to assess operators who may be exposed to musculoskeletal loading, which is known to contribute to upper limb disorders and associates with a scoring system that provides an indication of the level of loading experienced by the individual body parts. RULA has the advantage of providing a quick method for screening a large

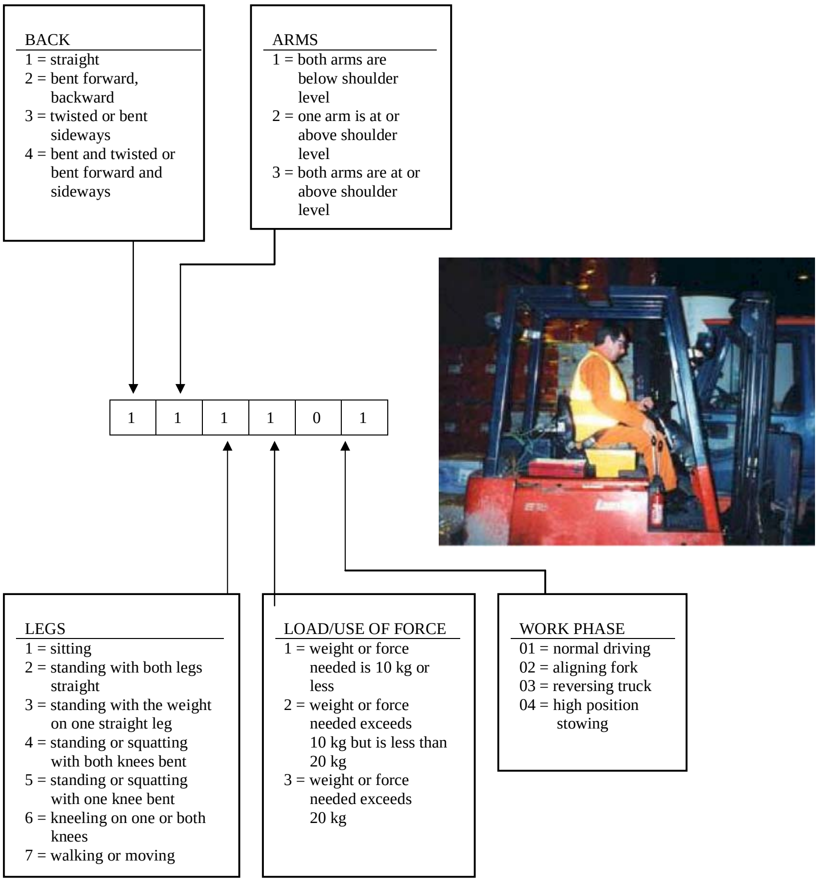

Fig. 1. Items and illustration of posture coding in the OWAS technique.

number of operators. Like OWAS, RULA is performed without the need for any equipment, and has proved to be a reliable tool for work posture assessment [12]. According to the method, predefined ranges of upper limb, neck, back and leg posture and numerical values drawn from charts are used to determine a risk score for the observed posture (Fig. 2) such that when equal to 1, the best or most neutral posture is adopted and when equal to 4, the worst position is adopted. For the postures analysed, muscle use and force exerted were given a score of 1 and 0, respectively, since during driving, postures tend to be held quite steady or static and the driver tends to apply only little or no force [14]. The combination of scores C and D defines a grand score, which reflects musculoskeletal loading, associated with the posture and an action category.

WBV measurements in the three orthogonal axes (x-fore and aft, y-lateral and z-vertical) were carried out under 12 actual working conditions (including movement over and across the different ground surfaces and during performance of different tasks—stacking loads, picking up and loading trucks). The forklift drivers generally found movement from one surface to another, to be a main source of shock loading and they expressed concern for increased rattling of the fork when travelling in certain areas of the warehouse (within the vicinity of supporting columns). The drivers also identified that in recent months three trucks had to be taken out of service for repairs due to cracks in their safety frames. The measurements were done according to the recommendations of ISO 2631-1 standard [15], i.e., at the driver/seat interface using a tri-axial seat pad accelerometer (Liberty mutual whole-body vibration meter 2.0). The pad was placed on the seat below the driver's bottom and connected to a portable field computer system packaged in a rugged instrument case. For each test run condition, the case was securely positioned within the cabin of the truck and the recorded accelerations were acquired over a 5 min period. For the three axes of vibration exposure, the values for four measures (average linear [weighted root-mean-square (rms)] acceleration, peak acceleration, crest factor [ratio of peak to average acceleration] and vibration dose value [VDV]) were determined, as well as the fatigue-decreased proficiency (FDP) allowable exposure (hours and minutes).

Data analysis was performed with the statistical package SPSS 9.0 for windows. Continuous variables were summarised with the average (mean) as measure of central tendency and the standard deviation (SD) as measure of dispersion. Group differences were analysed by two-tailed

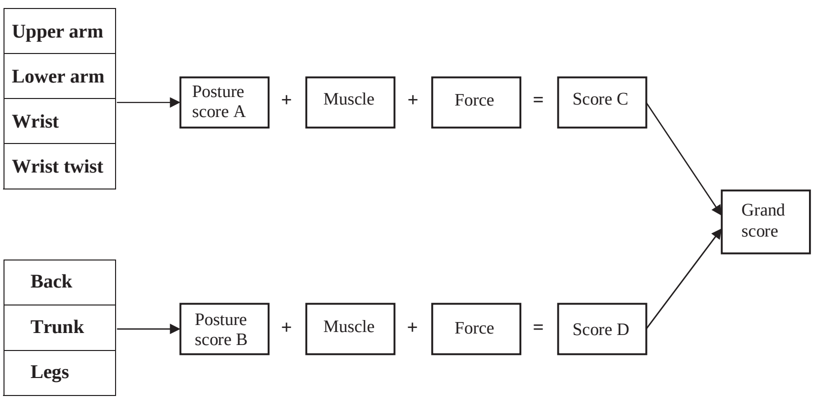

Fig. 2. Items and illustration and of posture scoring in the RULA technique.

Wilcoxon test and non-parametric sign test and $p < 0.05$ was accepted as the minimum for significance. Univariate odds ratios (OR) and 95% confidence intervals (CI) were computed to assess the relationship between occurrence of LBP and various risk factors, as the small sample size of respondents suggested that a log linear analysis was unlikely to produce results with high statistical reliability.

3. Results

The summarised anthropometric data for the forklift truck drivers and controls are presented in Table 1. As expected, the mean age of the forklift drivers and the controls was quite similar (44.4 and 44.9 years) though most of the workers were in the 30s and 50s age brackets. The average body mass index (BMI) values for the forklift drivers and controls also showed to be quite similar (26.5 and 25.6, respectively) and the distributions were skewed to the left.

3.1. Prevalence and intensity of LBP

LBP in the past 12 months was significantly more prevalent ($p < 0.05$) among the drivers than among the controls (15 [65.2%] and 8 [34.8%], respectively), with the drivers being more than twice as likely to have LBP (OR 3.516, 95% CI 1.044–11.828). LBP intensity also showed to be higher for the drivers than for the controls, with about 44% of the drivers reporting severe pain compared to about 22% of the controls who reported similar level of pain intensity (Fig. 3).

The persons with LBP were mainly in the 30–35 and 55–60 year old ranges (Fig. 4), but the mean ages for those with and without back pain were quite similar (45.0 and 44.3 years, respectively). When the data for controls and drivers aged 59 years and above were excluded, the mean age for those with back pain (drivers and controls) became 38.8 years and the mean age for those without back pain became 43.4 years. In respect of body weight, the average values for the drivers and controls did not differ significantly, but for those whose BMI was less than 25.0, LBP showed to be significantly more prevalent among drivers than among controls (Table 2).

3.2. Confounding factors

As can be seen in Table 2, increased OR were determined for exercise habit (1.3), lifting during work (2.2) and job satisfaction (1.4). A decreased odds ratio (0.9) was determined for smoking habit.

Table 1
Summarised anthropometric data (mean and (standard deviation)) for the forklift drivers and controls

Factors	Forklift drivers	Controls
Age	44.4 (13.01)	44.9 (12.48)
Height (m)	1.75 (0.06)	1.74 (0.11)
Weight (kg)	81.45 (10.11)	77.59 (11.77)
Body mass index (BMI)	26.5 (3.49)	25.6 (3.18)

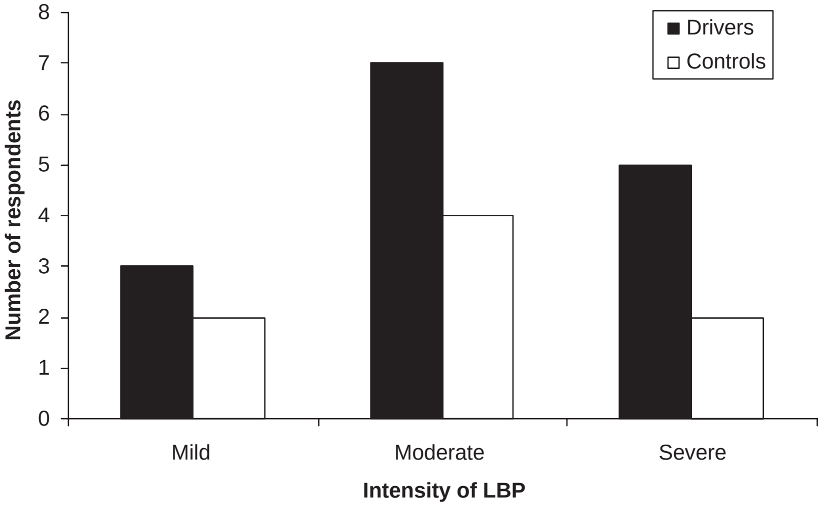

Fig. 3. Intensity of LBP for the controls ($N = 8$) and the forklift drivers ($N = 15$).

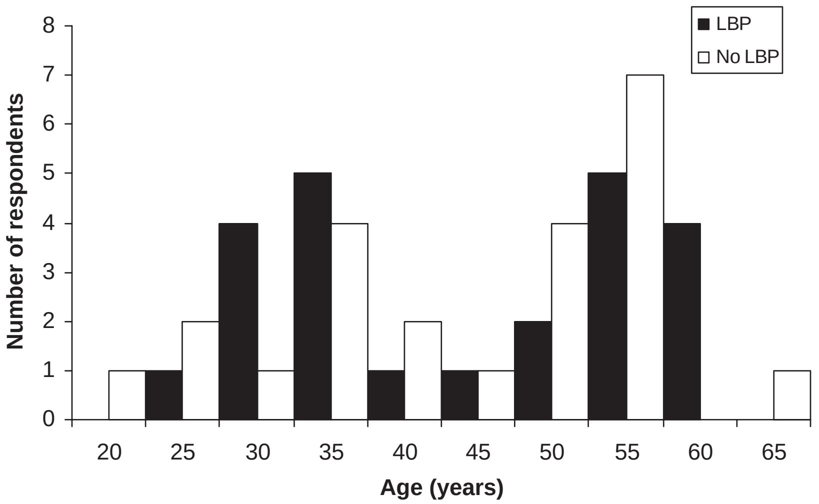

Fig. 4. Age of the respondents who reported LBP ($N = 23$) and no LBP ($N = 23$).

Smoking habit: For both the drivers and controls, there was a larger proportion of persons that smoked than did not, though at the time of interview, most persons had given up smoking. Indeed, 15 drivers indicated that they smoked (or had stopped smoking in the recent past 5 years), and 13 of the controls said they similarly smoked. Smoking habit, however, did not show to differ significantly between the drivers and controls nor did it show to relate significantly with prevalence of LBP (Table 2).

Exercise habit: There was a larger proportion of persons who engaged in regular exercise than did not. In this respect, 14 drivers indicated that they exercised regularly (at least once a week),

Table 2
Univariate odds ratios (OR), 95% confidence intervals (CI) for risk factors, between the two groups and association with LBP

Risk factor	OR	CI
Between the groups		
BMI (<25)	14.667	1.876–114.663
Lifts load	3.054	0.723–12.904
Exercise habit	0.549	0.157–1.919
Smoking habit	1.442	0.439–4.740
Association with LBP		
Occupation	3.516	1.044–11.828
Lifts loads	2.25	0.407–12.441
Exercise habit	1.333	0.223–7.931
Job satisfaction	1.426	0.442–4.600
Smoking habit	0.937	0.173–5.071

and 17 controls indicated that they similarly exercised regularly. The differences between the drivers and the controls in their exercise habit did not reach the significance level, nor did exercise habit show to relate significantly with prevalence of LBP (Table 2).

Job satisfaction: Of the 46 persons interviewed, 20% of those reporting previous episodes of back-pain showed to be dissatisfied with their jobs. As with smoking and exercise habit, job satisfaction did not show to relate significantly with prevalence of LBP (Table 2).

Lifting during work: A considerable number of drivers and controls (19 and 14, respectively) indicated that they performed lifting tasks as part of their jobs, though between the two groups, the amounts of lifting done did not differ significantly nor did lifting relate significantly with prevalence of LBP (Table 2). The stress from the manual load lifting, also showed to be mild, in that the reported frequencies of lifting were often less than five times a day and the weights of lifted load were generally less than 5 kg. However, two workers in the control groups did report quite intensive lifting and pushing (frequency > 10 times; loads > 5 kg) as part of their daily tasks and it was observed that the drivers tended to lift loads immediately following a period of continuous driving.

3.3. Posture and whole body vibration exposure

Fig. 5 presents the distribution of reported frequency of twisted and bent posture of the drivers while Table 3 presents the results of OWAS and RULA analyses on the four driving postures seen to be most frequently adopted. Fig. 6 shows the distribution of vibration exposure (hours per year of working life) for the drivers from the interview survey and Table 4 presents the summarised values of the measured forklift x-, y- and z-vibrations.

The drivers and controls differed in their working postures, with the drivers showing to sit more frequently and for longer without interruption than the controls. As illustrated in Fig. 5, 22 drivers indicated that they adopted the twisted trunk posture often or occasionally during driving and 18 indicated that they adopted the bent trunk posture with similar frequency. Both OWAS

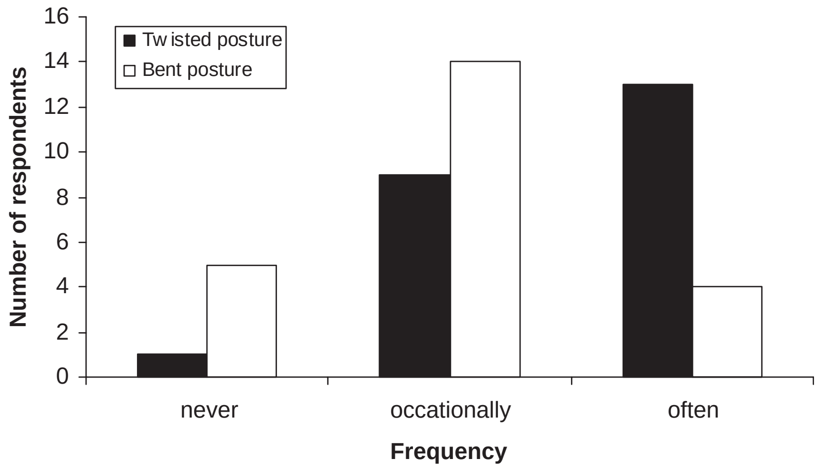

Fig. 5. Twisted and bent postures during forklift driving ($N = 23$).

Table 3
Results of analyses on the postures most frequently adopted by the forklift drivers

Work phase posture	Back score	Arm score	Leg score	Load/force score	Action category
(a) *By OWAS technique*					
Normal driving posture	1	1	1	1	1
Aligning forks posture	4	2	1	1	3
Reversing posture	4	2	1	1	3
Stowing posture	4	2	1	1	3

	Action category	
	Right side limbs	Left side limbs
(b) *By RULA technique*		
Normal driving posture	2	2
Aligning forks posture	3	3
Reversing posture	3	3
Stowing posture	3	3

Note:

- Action category 1 indicates that posture is acceptable.
- Action category 2 indicates further investigation/changes may be required.
- Action category 3 indicates investigation/changes are requires soon.
- Action category 4 indicates investigation/changes are required immediately.

and RULA analyses showed that three of the four driving postures were potentially harmful, i.e., the aligning forks posture, the reversing posture and the high position stowing posture (Table 3). The normal driving posture was found to be acceptable, by both, though RULA analyses showed there were indications of potential hazard in the adopted postures of the upper limb.

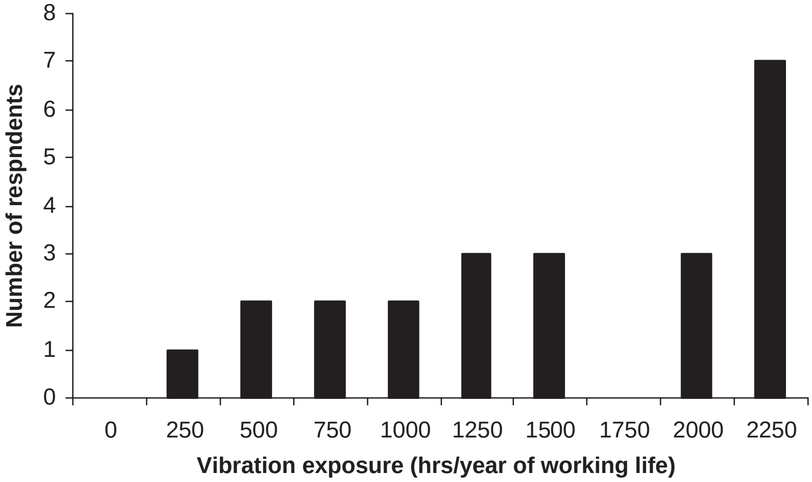

Fig. 6. Vibration exposure for the forklift drivers ($N = 23$).

Table 4
Summarised values of measured forklift truck vibration (mean acceleration [mean], peak acceleration [peak], vibration dose value [VDV], crest factor [CF], FDP exposure duration [FDP])

Measures	*X*-axis		*Y*-axis		*Z*-axis	
	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
Mean (m/s^2)	0.18–0.44	0.31 (0.072)	0.17–0.50	0.29 (0.089)	0.32–0.73	0.57 (0.124)
Peak (m/s^2)	2.10–4.69	3.35 (0.848)	2.10–5.47	3.37 (1.186)	1.24–24.46	13.53 (6.351)
VDV ($m/s^{1.75}$)	9.84–21.15	15.47 (3.443)	9.53–27.20	15.41 (5.162)	23.91–44.87	33.94 (7.837)
CF	6.86–14.91	11.08 (2.252)	7.59–22.83	12.01 (4.507)	8.10–65.58	26.54 (17.228)
FDP (h)	7.49–>24		6.31–>24		3.06–18.13	

In relation to whole body vibration exposure, the 23 drivers were exposed to vibration for between 250 and 2250 h during their working life (Fig. 6). Of these, 16 indicated that they experienced discomfort from vibration in the vertical (z-axis) direction, 12 indicated that they experienced discomfort from vibration in the lateral (side-to-side y-axis) direction and 8 indicated that they experienced discomfort from vibration in the fore-aft (x-axis) direction.

Furthermore, the vibration measurements showed that the average rms acceleration values in x- and y-axis were below the EU Physical Agents Directive on Vibration Exposure recommended action level ($0.5\,m/s^2$) across all the measured conditions, but not in the z-axis (Table 4). The computed ISO FDP exposure duration averaged 12 h for the z-accelerations, though in 10 of the 12 measured conditions the values were less than 8 h and within the recommended caution zone. The exposure durations averaged 21 h for the x- and y-accelerations, respectively, and it was in only one of the 12 measured conditions that the value was less than 8 h. Though considerably high crest factors (>9.0 and indicative of included shocks) were determined for most of the x-, y- and z-accelerations, only the z-accelerations were associated with considerably high VDV values ($>15\,m/s^{1.75}$), and that was in all the 12 measured conditions. The x- and y-acceleration were, respectively, associated with appreciably high VDV values in five of the 12 measured conditions. The results also showed that the axial vibrations tended to occur with frequencies between 5 and 7 Hz.

4. Discussion

WBV exposure and posture were investigated using both questionnaire and objective measurements for insights into how they currently occur for drivers of forklift trucks. The intention was to evaluate the associated risks for LBP.

As with all cross-sectional studies, however, collection of the data presented some drawbacks. First is the fact that the prevalence of LBP might have been underestimated. Indeed, since interviews were conducted on site a selection of healthy workers was probably made, as those on sick leave at the time could not have been considered (the healthy-worker effect). Second concerns the representativeness of the information collected on previous experience of LBP and exposure to risk factors. These may not have been precise, since a retrospective questionnaire such as that used, can only partially reconstruct history and the possibility of bias in how each of the four interviewers interpreted the questions to respondents cannot be ruled out. Despite these drawbacks, the fact that face-to-face interviews were used to obtain the questionnaire responses, alongside direct observation of the workers during their work, means that the data collected are more accurate and complete than what would have been possible from questionnaires completed solely by the workers. Also, the validity of health and morbidity information collected by questionnaire instruments has been demonstrated in several retrospective studies [16].

The findings of the present study reflect those of other works. Shinozaki et al. for example, reported an initial 63% prevalence of LBP amongst forklift operators, which was significantly higher than that found among non-driving blue-collar workers (32%) and white-collar workers (22%) [17]. Boshuizen et al. found that young drivers, <35 years, had a higher prevalence (68%) of both short- and long-lasting back pain than did a reference group of non-drivers (25%) though with increasing age the higher prevalence disappeared and the drivers drove for short times only [3]. Magnusson et al. reported 50% prevalence of LBP among their group of studied drivers as well as a significant relationship between lifting-in-job and LBP [18]. The work also identified that combination of long-term vibration exposure and frequent lifting presents the highest risk for LBP.

In a typical 8 h workday, it was observed that the forklift drivers spent between 4 and 6 h actually driving and tended to lift loads immediately after some period of continuous driving. Also, aside from statutory break periods for tea/coffee and dinner, the drivers did not show to take any other rest breaks during the working time. Though posture was not found to relate significantly with reported LBP, the forklift drivers were observed to adopt awkward (twisted or bent trunk) postures quite frequently during their work and in themselves the postures adopted showed to be associated with high potential risk. These factors characterise a potentially hazardous work situation. Relative to the vibration exposure, quite low magnitudes of vibration were determined, particularly in the x- and y-axis. In fact, the average accelerations show to be lower than those reported in earlier studies [19–22]. Malchaire et al. [22] showed quantitatively that the roughness of the track, the speed of movement and quality of the seat are the factors that mainly influence the vibration exposure. Inflated tyres were also found to be preferable when an anti-vibration seat with a very low resonance frequency is used. It may then be that the design of forklift trucks have improved over the years to encourage lower levels of vibration or that the forklift studied were operated in less severe conditions than those in the other studies. However, since in the present study the measures were not analysed to identify effects of different vehicle and task factors, these comments are only speculative and not conclusive. Notwithstanding, it is clear that exposure to whole body vibration is common during forklift driving work, but as has been suggested previously by Palmer et al. [2], exposure to only a small proportion of the exposures is likely to exceed the action level proposed in standards.

Little risk was suggested from the point of FDP allowable exposure, but there were strong indications that severe shock loadings were prevalent and the vibrations showed to occur at frequencies similar to the natural frequency of the human body, i.e., between 5 and 7 Hz. These findings suggested that there is a great potential of musculoskeletal injury for forklift drivers who are exposed for long periods and engage in manual handling tasks [23]. Indeed, after long exposure to whole body vibration, muscle response to sudden loading has greater latency [24] and fatiguing of the back muscle has been suggested for repetitive (>50 times) performance of handling tasks (for example [25]). Furthermore, considerable muscle effort may be required to keep the back strengthened particularly when seated postures in which the trunk is deviated or twisted more than 20° are adopted [26]. It is therefore likely that the forklift drivers studied, developed LBP due to reduced strength and/or stability at the lumbar area from muscle fatigue induced during whole body vibrations, particularly during situations of sudden lumbar loading such as unduly rapid rate of task performance or load handling in awkward postures. This may also explain why an increased OR was found for the association between lifting-in-job and LBP even though the workers performed only mild handling.

5. Conclusions

This study was conducted to investigate the risks from WBV and posture for LBP among forklift truck drivers. The measured vibration exposures suggested the presence of severe shock loading, and the results indicated that WBV acts associatively with other factors (not independently) to precipitate LBP. Based on the stated objectives the following conclusions are made.

1. LBP is more prevalent amongst forklift drivers than non-driving workers.
2. Driving postures in which the trunk is twisted or bent forward considerably and/or the neck extended backward, associate with greatest risks for LBP.
3. Acceptable levels of vibration exposure (i.e., below the EU Physical Agents Directive on Vibration Exposure recommended action level—$0.5\,\mathrm{m/s^2}$) are generated by forklift trucks in the x- and y-directions, but not in the z-direction.

Acknowledgements

The work reported is part of a larger study, which is being funded by the Health and Safety Executive, UK. The authors gratefully acknowledge this support. Our thanks also go to the

Liberty Mutual Research Centre for Safety and Health, Hopkinton, Massachusetts, USA for the whole body vibration meter made available to the project team.

References

[1] European Parliament and the Council of the European Union, OJ L177, 6.7.2002 Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration), *Official Journal of the European Communities*, 2002.

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

[3] H.C. Boshuizen, P.M. Bongers, C.T.J. Hulshof, Self-reported back pain in fork-lift truck and freight-container tractor drivers exposed to whole-body vibration, *Spine* 17 (1992) 59–65.

[4] J.A. Lines, R.M. Stayner, Ride vibration: reduction of shock arising from over-travel of seat suspensions, Health and Safety Executive Contract Research, Report 240/2000, 2000.

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

[6] B. Rehn, I.A. Bergdahl, C. Ahlgren, C. From, B. Jarvholm, Musculoskeletal symptoms among drivers of all-terrain vehicles, *Journal of Sound and Vibration* 253 (2002) 21–29.

[7] K. Omino, Y. Hayashi, Preparation of dynamic posture and occurrence of low back pain, *Ergonomics* 35 (1992) 693–707.

[8] M.L. Magnusson, M. Pope, A review of the biomechanics and epidemiology of working postures (it isn't always vibration which is to blame), *Journal of Sound and Vibration* 215 (1998) 965–976.

[9] J.I. Kuiper, A. Burdorf, J.H.A.M. Verbeek, M.H.W. Frings-Dresen, A.J. van der Beek, E.R.A. Viikari-Juntura, Epidemiological evidence on manual materials handling as a risk factor for back disorders: a systematic review, *International Journal for Industrial Ergonomics* 24 (1999) 389–404.

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

[11] M.L. Magnusson, M. Pope, C.T.J. Hulshof, M. Bovenzi, Development of a protocol for epidemiological studies of whole-body vibration and musculoskeletal disorders of the lower back, *Journal of Sound and Vibration* 215 (1998) 643–651.

[12] J.R. Wilson, E.N. Corlett (Eds.), *Evaluation of Human Work*: *A Practical Ergonomics Methodology*, second ed., Taylor and Francis, London, 1995.

[13] L. McAtamney, E.N. Corlett, RULA: a survey method for the investigation of work-related upper limb disorders, *Applied Ergonomics* 24 (1993) 91–99.

[14] M. Massaccesi, A. Pagnotta, A. Soccetti, M. Masali, C. Masiero, F. Greco, Investigation of work related disorders in truck drivers using RULA method, *Applied Ergonomics* 34 (2003) 303–307.

[15] International Organisation for Standardisation, International Standard 2631-1, Mechanical vibration and shock—evaluation of human exposure to whole-body vibration—part 1: general requirements, 1997.

[16] J. Meyer, D. Flenghi, J. Deschamps, Effects of manual handling, posture and whole body vibration on low back pain, *International Journal of Occupational Safety and Ergonomics* 4 (1998) 449–470.

[17] T. Shinozaki, E. Yano, K. Murata, Intervention for prevention of low back pain in Japanese forklift workers, *American Journal of Industrial Medicine* 40 (2001) 141–144.

[18] M.L. Magnusson, M.H. Pope, D.G. Wilder, B. Areskoug, Are occupational drivers at an increased risk for developing musculoskeletal disorders?, *Spine* 21 (1996) 710–717.

[19] H. Dupuis, G. Zerlett, *The Effects of Whole-Body Vibration*, Springer, Berlin, 1986.

[20] M.J. Griffin, *Handbook of Human Vibration*, Academic Press, London, 1990.

[21] P. Donati, T. Ward, S. Critchlow, *Effect of Tyres on Whole-Body Vibration in Two 1.5 ton Counterbalance Forklift Trucks*, Institut National de Recherche et de Securite, Paris, 1993.
[22] J. Malchaire, A. Piette, I. Mullier, Vibration exposure on fork-lift trucks, *Annals of Occupational Hygiene* 40 (1996) 79–91.
[23] M.L. Pope, T. Hansson, Vibration of the spine and low back pain, *Clinical Orthopaedics and Related Research* 279 (1992) 49–59.
[24] M.H. Pope, D.G. Wilder, M. Magnusson, Possible mechanisms of low back pain due to whole-body vibration, *Journal of Sound and Vibration* 215 (1998) 687–697.
[25] P. Dolan, M.A. Adama, Repetitive lifting tasks fatigue the back muscles and increase the bending moment acting on the lumbar spine, *Journal of Biomechanics* 31 (1998) 713–721.
[26] A. Toren, Muscle activity and range of motion during active trunk rotation in a sitting posture, *Applied Ergonomics* 32 (2001) 583–591.