

Whole Body Vibration Exposures in Long-haul Truck Drivers

Many professional truck drivers experience low back pain (LBP) which is believed to be associated with exposure to whole body vibration (WBV). As a part of a randomized controlled trial, this study measured WBV exposures from 98 professional truck drivers continuously during their regular work shift (8-12 hours). The daily weighted average A(8), vibration dose value VDV(8), and vector sum A(8) and VDV(8) exposures were evaluated for important determinants of WBV exposures including the roads travelled on, year of truck manufacture, truck manufacturer, and seat manufacturer. LBP was also measured using a standardized visual analog scale. The results demonstrated that there were substantial differences in health risk prediction between the predominant axis exposure (advocated by the European Union Vibration Directives) and vector sum exposures. Moreover, VDV(8) measures were above the International Organization for Standardization and European Union daily exposure action limit (9.1 m/s^2). The average LBP score on a 0 to 10 point scale was 2.7 (SD: 2.04) ranging from 0 to 8. When comparing the two major manufacturers of truck seats, one truck seat had higher vertical, z-axis A(8) exposures than the other (24%, $p = 0.01$); and this WBV exposure difference appeared to be reflected by the LBP outcomes. These results indicate that truck drivers' impulsive WBV exposure can exceed recommended daily action limits and there are performance differences between seats in the attenuation of WBV exposures.

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) have been the single largest component of nonfatal occupational injuries and illnesses (BLS 1992-2011). Among work-related musculoskeletal disorders, low back pain (LBP) is the most common worker's compensation claim (Rauser et al., 2008). LBP is also the most common cause of persistent disability claims and continues to be the leading cause of morbidity and lost productivity in the workplace (Ammendolia et al., 2009).

Previous studies have shown that exposure to whole body vibration (WBV) is a leading risk factor for occupational LBP in professional vehicle operators (Bovenzi, 1996). Increased spinal load and intervertebral disc degeneration have also been identified as possible mechanisms for WBV-related LBP (Fritz, 2000).

Due to the long driving hours, long-haul truck drivers in the United States are likely to be exposed to continuous WBV for prolonged periods of time, up to 12 hours a day and 70 hours a week. Professional truck drivers have ranked second among all the occupations in number of non-fatal occupational injuries and illnesses and the low back is the region most often affected.

Although there have been studies that have identified factors affecting WBV exposures in various

vehicles including buses, forklifts, small and large trucks (Blood et al., 2010a; Johnson and Blood, 2011; Thamsuwan et al., 2013), there has been limited research to determine the factors affecting WBV exposure in heavy, long-haul truck drivers in real field settings. Therefore, the purpose of this study was to characterize WBV exposures during regular truck driving (8-12 hours) and determine whether there are any factors (truck manufacturer, year of truck manufacture, and seat manufacturer) which may affect WBV exposures.

METHODS

Subjects

As a part of series of baseline measurements for a randomized controlled trial study, a total of 98 professional truck drivers from five different trucking companies were recruited through the support from Washington State Trucking Association. All the subjects were experienced truck drivers that had at least one year of employment with the current company they were employed. All participating drivers were either regional or line-haul drivers; meaning they spent the majority of their day behind the wheel driving and starting and returning to their terminal within a 24 hour

period. In addition, all recruited drivers were classified as “no-touch” drivers, which implied they primarily did not handle or lift cargo unless absolutely necessary. The experimental protocol was approved by the University’s Human Subject Committee and all subjects gave their informed consent before their participation in the study.

Experimental design

The WBV exposure data were collected during their regular work schedule (8-12 hours). According to International Organization for Standardization (ISO) 2631-1 whole body vibration standards, a tri-axial seat-pad accelerometer (Model 356B40; PCB Piezotronics; Depew, NY) was mounted on the driver’s seat and either an identical tri-axial or single axis (z-axis) accelerometer (Model 352C33; PCB Piezotronics; Depew, NY) was magnetically mounted to the floor of the truck cab beneath the driver’s seat (Fig. 1). Acceleration data were collected at 1,280 Hz using either a four or eight channel data logger (Model DA-20 or DA-40; Rion Co. LTD; Tokyo, Japan). Vehicle speed and location were simultaneously recorded at 1 Hz using a GPS logger (Model DG-100; GlobalSat; Chino, CA).



Figure 1. Data acquisition system.

From a subset of 62 drivers who indicated current LBP, LBP outcomes were collected using a standardized visual analog scale. The scale ranged from 0 to 10 with verbal anchors: 0 being “no pain” and 10 being “worse pain you can imagine.” Drivers were asked to rate the level of their back pain when it was at the worst in the past week.

Lastly, to identify important determinants of WBV exposures, subject’s demographics and truck information including truck manufacturer, year of truck manufacture, and seat manufacturer were also collected. The two major truck seats manufacturers represented in this study accounted for approximately 76% of all the seat manufacturers in this study: National Seating (Mfg 1) and Sears Seating (Mfg 2).

Data analysis

A LabVIEW program (v2012; National Instruments; Austin, TX) was used to parse the acceleration data based on GPS coordinates and then calculate the weighted average vibration exposures (A_w) and vibration dose values (VDV) as follows:

- Root mean square (r.m.s) weighted average acceleration (A_w) calculated at the floor and at the seat (m/s^2):

$$A_w = \sqrt{\frac{1}{T} \int_0^T a_w^2(t) dt}$$

where,

$a_w(t)$: instantaneous weighted acceleration at time t ;
 T : duration of measurement in seconds.

- Vibration dose value (VDV), which is more sensitive to impulsive vibration ($m/s^{1.75}$):

$$VDV = \left[\int_0^T a_w^4(t) dt \right]^{\frac{1}{4}}$$

Both A_w and VDV values were normalized to reflect 8 hours of driving exposure (e.g. $A(8)$ and $VDV(8)$). To determine health effects, as outlined in ISO 2631-1 whole body vibration standard, the frequency weightings were applied to the fore-aft (x) and lateral (y) axes by multiplying by 1.4. The vector sum value (Σ) was also calculated as a measure of the total WBV exposure value as follows:

$$A(8)_{\Sigma} = \sqrt{(1.4 A(8)_x)^2 + (1.4 A(8)_y)^2 + (1.4 A(8)_z)^2}$$

$$VDV(8)_{\Sigma} = \sqrt[4]{(1.4 A(8)_x)^4 + (1.4 A(8)_y)^4 + (1.4 A(8)_z)^4}$$

Multiple linear regression models (JMP Version 9; SAS Institute; Cary, SC) were used to identify significant determinants which may affect WBV exposures. The hypothesized explanatory variables included road segment, truck manufacturer, year of truck manufacture, and seat manufacturer. Due to the non-normality of the LBP data, *Kruskal-Wallis* tests were used to determine the differences in LBP between the seat manufacturers. Statistical significance was noted when p-values were less than 0.05.

RESULTS

The WBV exposure measures from all three axes are summarized in Table 1. The results showed that the vertical (z) axis was the predominant exposure and that single-axis seat-measured A(8) exposures were below the ISO and European Union (EU) daily action limit values (0.5 m/s^2). However, vector sum A(8) exposures (0.55 m/s^2) were above the action limit. By comparing the vertical vibration measured at the seat and floor, the ratio of the A(8) exposures showed that approximately 89% of the floor-measured vibration was transmitted to the drivers.

The seat-measured VDV(8) values were all above the ISO and EU action limit ($9.1 \text{ m/s}^{1.75}$). The results showed that VDV(8) values on the seat were 29-32% higher than the floor-measured values, indicating the seats amplified rather than attenuated the impulsive WBV exposures.

Table 1. Mean (SE) A(8) and VDV(8) single axis and vector sum (Σ) WBV exposures [n = 98].

		Seat		
		Floor	Seat	P-value*
A(8)	1.4X	0.18 (0.01)	0.27 (0.02)	0.002*
	1.4Y	0.19 (0.01)	0.29 (0.01)	0.001*
	Z	0.40 (0.02)	0.36 (0.01)	0.029*
	Σ	0.46 (0.02)	0.55 (0.02)	0.004*
VDV(8)	1.4X	8.8 (0.7)	11.4 (0.7)	0.004*
	1.4Y	9.9 (0.9)	13.1 (0.8)	0.001*
	Z	9.3 (0.2)	12.2 (0.3)	0.001*
	Σ	18.6 (3.5)	19.6 (1.2)	0.957

*P-values were calculated from multiple linear regression and statistical differences are denoted by asterisks. Bold numbers indicate “above action limits”: A(8) > 0.5 m/s^2 and VDV(8) > $9.1 \text{ m/s}^{1.75}$.

There were no systematic differences in WBV exposure between truck manufacturer and year (p-values >> 0.05); however, there were differences between road segments (p-values < 0.05, not shown) and seat manufacturers (Table 2). With seat manufacturer 2, the vertical A(8) WBV exposures were 24% lower compared to seat manufacturer 1 (p=0.01) whereas there were no differences in the other axes of exposure. For both seat manufacturers, the vector sum A(8) values were above the action limits. On the other hand, VDV(8) values did not differ between the seats; however, the single axis and vector sum exposures were above the daily action limits.

The average LBP score was 2.7 (SD: 2.04) ranging from 0 to 8 (n = 62). The LBP outcomes were compared between two major seat manufacturers: manufacturer 1 (n=33) vs. manufacturer 2 (n=14) as shown in Table 2. For the other 15 seats, the manufacturers were either unknown or very few. Although the difference was not statistically significant, the drivers using a seat from manufacturer 1 had approximately 20% higher LBP compared to those using a seat from manufacturer 2.

Table 2. Mean (SE) A(8) and VDV(8) single axis and vector sum (Σ) exposures by axis when grouped by seat manufacturer [n = 98]. Mean (SE) low back pain scores (0-10 scale) measured using the visual analog pain scale [n=62].

		Seat		
		Mfg 1 [n = 72]	Mfg 2 [n =26]	P-Value*
LBP		2.6 (0.3)	2.2 (0.6)	0.31
A(8)	1.4X	0.26 (0.01)	0.27 (0.06)	0.97
	1.4Y	0.29 (0.01)	0.28 (0.02)	0.73
	Z	0.38 (0.01)	0.29 (0.02)	0.01*
Vector Sum		0.56 (0.02)	0.52 (0.05)	0.41
V(8)	1.4X	10.9 (0.8)	9.5 (1.4)	0.76
	1.4Y	11.6 (0.8)	12.8 (1.4)	0.23
	Z	12.9 (0.4)	9.8 (0.6)	0.22
Vector Sum		18.6 (0.4)	17.7 (0.6)	0.81

*P-values for LBP was calculated from the Kruskal-Wallis test and statistical differences are denoted by asterisks. Bold numbers indicate “above action limits”: A(8) > 0.5 m/s^2 and VDV(8) > $9.1 \text{ m/s}^{1.75}$.

DISCUSSION

The main goal of the present paper was to characterize and compare the WBV exposures in truck drivers across different road segments trucking companies, truck manufacturers, manufactured year, and seats.

Relative to ISO and EU Daily Action Limits (0.5 m/s^2 for A(8) and $9.1 \text{ m/s}^{1.75}$ for VDV(8)), there was a substantial difference in risk prediction between the predominant z-axis and vector sum WBV exposures. The results showed that the single-axis A(8) WBV exposures were acceptable based on the ISO and EU standards (0.5 m/s^2); however, the vector sum WBV exposures were above the action limits.

The VDV(8) parameter is a cumulative measure which is more sensitive to impulsive exposures. The

results demonstrated that all the single-axis and vector sum VDV(8) WBV exposures were above the ISO and EU action limits ($9.1 \text{ m/s}^{1.75}$), indicating that truck drivers must be experiencing some impulsive shocks during their regular work. Previous studies have shown that exposures to the transient shock component could contribute to the degeneration of lumbar spine more than the continuous steady state component (Mayton et. al., 2008). Moreover, the truck seat suspension appeared to have limited performance and actually amplified the impulsive, VDV(8) WBV exposures (Table 1). This is in line with the previous studies (Blood et. al., 2010).

This study also found that the WBV exposures differed between the seat manufacturers. The vertical A(8) was 24% lower when results from the two seat manufacturers were compared (Table 2). Moreover, despite a lack of statistical significance, there was also approximately a 24% difference in vertical VDV(8) WBV exposures between seats. Interestingly, these trends in vertical WBV exposure differences appear to be mirrored in the LBP differences observed between the seats. A limitation and caution to this interpretation is the cross-sectional assessment of the WBV exposures and LBP.

In this study, as the WBV measurements were made during the drivers' full shift (8-12 hours), compared to the WBV exposure measured for a short period from simulated or standardized routes, these WBV exposures should be more representative for long-haul truck drivers. However, this study also has some limitations. Even though we noted the possible relationships between lower WBV exposures and lower LBP, this result cannot be interpreted as a causal relationship because these results are based on the cross-sectional analysis. Therefore, subsequent prospective studies to further evaluate this association are merited.

In conclusion, this study identified differences in health risk prediction between the predominant axis and vector sum A(8) WBV exposures. The predominant axis approach showed the A(8) WBV exposure level was acceptable whereas the vector sum exposures were always above daily action limits. The bottom line is that the truck drivers evaluated in this study appear to have moderate to high exposures to WBV. Moreover, the impulsive WBV exposures VDV(8) appeared to be more prominent (above the action limit) than the average vibration exposures. Finally, based on the exposure difference between seat manufacturers, this study indicated there may be an association between the vertical A(8) WBV exposures and levels of LBP, but further research is merited. Therefore, these results indicate that the vertical exposure may have a greater association with LBP outcomes, and based on the differences observed, that the A(8) exposure may have a

stronger link to LBP than the impulsive VDV(8) measures.

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