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Article · September 2016
DOI: 10.1177/1541931213601214

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Comparing the Whole Body Vibration Exposures across Three Truck Seats

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Studies have shown that there are differences in whole body vibration (WBV) exposures and WBV attenuation performance among different suppliers of air suspension truck seats. With 17 truck drivers operating semi-trucks over two common road types (the same highways and dirt roads), WBV exposures were measured and compared across three different air-suspension truck seats. Similar to a previous study, in the higher-speed, on-road highway conditions, one seat was found to have higher WBV exposures and lower WBV attenuation performance. In off-road conditions at slower speed, there were negligible differences across the three seats. These differences in seat performance have important practical implications. The higher performing seats nearly doubled the amount of time drivers could operate their trucks before reaching the ISO daily vibration action limits from 3 to 6 hours a day to 9 to 11 hours a day. Seat suspension-based design differences are thought to account for the performance differences.

INTRODUCTION

It is believed that exposure to whole-body vibration (WBV) is associated with several adverse health outcomes including low-back pain and driver fatigue, which may contribute to vehicle-related accidents (Conway, 2007). In order to reduce WBV exposure and mitigate potential adverse health outcomes, trucks are increasingly fitted with higher quality vibration-damping seat technologies. One such seat is an active suspension truck seat which has been shown to reduce WBV exposures up to 50% relative to the industry standard air-suspension seat (Blood et al., 2011).

A recent randomized controlled trial study showed that the reduced WBV via the active suspension seat resulted in reduction in self-reported LBP, whereas no LBP was seen in drivers receiving the new industry-standard air-suspension seats (Kim et al., 2015). Their study results suggest that the active suspension seat may have the potential to improve truck drivers' musculoskeletal health outcomes. However, the challenge with the active suspension seats is the substantial costs relative to the industry standard air suspension seats, making trucking companies and truck owner-operators reluctant to purchase the more expensive active suspension seat.

The objective of this study was to evaluate the efficacy of three commercially-available air-suspension truck seats for reducing truck drivers' exposures to WBV in order to provide recommendation and/or guidelines for seat manufacturers, trucking industries, and truck drivers.

METHODS

Seventeen truck drivers with mean age 49.3 years (range 35-64) were recruited for this study. Study procedures were approved by the University's IRB board and all truck drivers gave their informed consent. Three seats were evaluated and compared in this study, one seat was the trucking company's existing seat, which was tested in 9 different trucks, and on average these seats were 12 months old (Seat 1 – Model National Premium; Commercial Vehicle Group; Columbus OH). The other two seats were brand new and serially installed and tested in the same truck on two separate days (Seat 2 – Model Elite; Sears Seating; Davenport, IA and Seat 3 – Model 6860/875 NTS; Isringhausen; Detroit, MI). Seat 2 and Seat 3 are both aftermarket truck seats available in North America.

According to ISO 2631-1 WBV standards, WBV exposures were collected at 1280 Hz from the seat and the floor of the trucks using tri-axial accelerometers (Model 356B40; PCB Piezotronics; Depew, NY) over the drivers' 10-hour full shift. In addition, truck speed and location data were collected every second using a GPS tracking device (Model CR Q1100P; Qstarz; Taipei, Taiwan).

The trucks transported raw aggregate material from two mines to a shipping port in British Columbia, Canada. WBV exposures from the three seats were compared over the whole routes. Also, using the GPS data, we compared WBV exposures across three seats when travelling over two different road types: paved highways and unpaved roads. All trucks drove on the same 148.9 km segment of highway to and from the mines. However, since the relatively short 2.56 km off-road unpaved segments were different between the two mines, the off-road WBV exposures from only one mine were compared across the three seats.

Average weighted vibration (A_w) and Vibration Dose Values (VDV) were calculated and normalized to eight hours of exposures (e.g. A(8) and VDV(8)) to facilitate comparisons by seat and road type.

The 8 hour average weighted WBV exposures A(8) were calculated at the floor and seat top (units m/s^2):

$$A(8) = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{\frac{1}{2}} \quad (1)$$

The 8 hour cumulative-impulsive VDV(8) WBV exposures, which are more sensitive to jolts and shocks, were calculated using the following formula (units $m/s^{1.75}$).

$$VDV(8) = \left[\int_0^T [a_w(t)]^4 dt\right]^{\frac{1}{4}} \quad (2)$$

In addition, the Seat Effective Amplitude Transmissibility (SEAT) was calculated as the ratio of the seat-measured vibration divided by the floor-measured vibration, which gives a measure of how much vibration the seat attenuates.

Finally, using the exposures normalized to represent 8 hours of driving (A(8) and VDV(8)), the truck operation time to reach the ISO 2631-1 daily vibration action limits (DVAL) were derived using the following formula:

$$\left(\frac{Action\ limit}{Exposure(8)}\right)^n \times 8 \quad (3)$$

When Exposure (8) = A(8),
Action Limit = 0.5 m/s^2 and n = 2;

When Exposure (8) = VDV(8),
Action Limit = 9.1 $m/s^{1.75}$ and n = 4.

The WBV exposures above action limits indicate that the likelihood of adverse health outcomes increases. Repeated measures linear mixed models were used to determine whether there were differences in WBV exposures across the three seats.

RESULTS

Figure 1 shows the seat-measured A(8) and VDV(8) WBV exposures by axis over the whole route. Since there was not a significant seat by axis interaction, results were averaged across all seats. As can be seen in Figure 1, the z-axis was the predominant axis of exposure. Since ISO standards recommend reporting of the predominant axis exposures, only z-axis analysis will be reported in the subsequent results.

Table 1 shows the mean z-axis floor and seat WBV exposures, and SEAT values over the whole route. As shown in Table 1, the WBV exposures measured from Seat 1 were significantly higher than Seat 2 and Seat 3 and all seat-measured WBV exposures were above the recommended ISO DVALs. The SEAT values indicated that all three Seats reduced the WBV exposures between 9 and 25%, but no significant differences in SEAT values across seats were found over the whole routes.

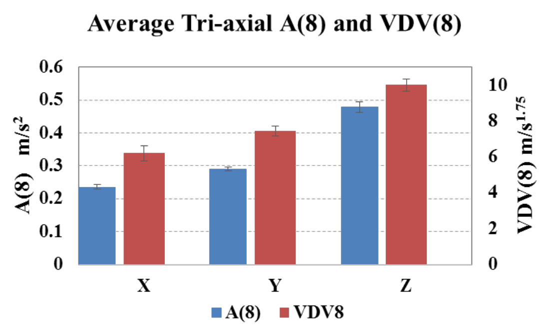

Figure 1. Mean (±SE) tri-axial seat-measured A(8) and VDV(8) WBV exposures over the whole route (n = 41).

Table 1. Mean (± SE) z-axis seat- and floor-measured WBV exposures, and the corresponding SEAT values over the whole route. The ISO DVALs are below the WBV exposure parameters in parenthesis.

Parameter	Location	Seat 1 (n = 16)	Seat 2 (n = 13)	Seat 3 (n = 12)	p-value
A(8) (0.5 m/s^2)	Floor	0.57^{a} (0.01)	0.52^{b} (0.01)	0.53^{b} (0.01)	0.007
	Seat	0.55^{a} (0.02)	0.43^{b} (0.03)	0.44^{b} (0.01)	<0.0001
	SEAT	0.91 (0.04)	0.81 (0.05)	0.82 (0.02)	0.0958
VDV(8) (9.1$m/s^{1.75}$)	Floor	13.0^{a} (0.2)	11.9^{b} (0.3)	12.0^{b} (0.2)	0.0011
	Seat	11.3^{a} (0.4)	9.1^{b} (0.7)	9.3^{b} (0.4)	<0.0001
	SEAT	0.83 (0.04)	0.76 (0.05)	0.75 (0.03)	0.2793
Speed (km/h)	—	61.9 (0.7)	59.7 (1.2)	59.7 (1.8)	0.23

Values with different superscripts across rows are significantly different

Figure 2 graphically shows the results from the two common road types encountered by the truck drivers, the paved highways and unpaved roads. As can be seen in Figure 2, there were significant differences across seats in the z-axis A(8) and VDV(8) measures on the highways, with Seat 1 subjecting the truck drivers to the greatest WBV exposures. WBV exposures from the unpaved road segment were significantly higher than the highway segment. All WBV exposures from the unpaved road were above DVALs with no differences in WBV exposures across the three seats.

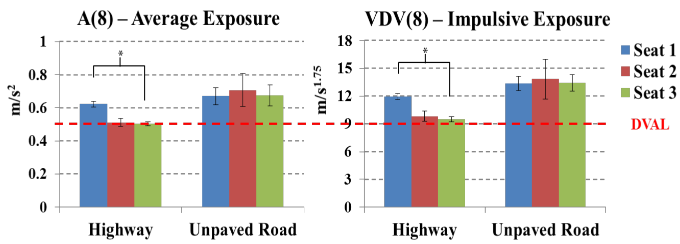

Figure 2. Mean (± SE) z-axis seat-measured A(8) and VDV(8) WBV exposures by road type.

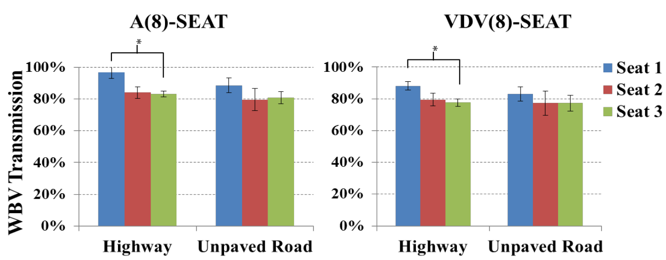

Figure 3. Mean (± SE) z-axis A(8) and VDV(8) SEAT values by road type.

In Figure 3, the mean A(8) and VDV(8) SEAT values of Seat 1 were higher than Seat 2 and 3 on both paved highways and unpaved roads. On the paved highways, SEAT values of Seat 2 and Seat 3 were significantly lower that Seat 1, indicating better attenuating performance of the floor transmitted WBV exposures. No significant difference was found across the SEAT values on the unpaved roads.

Table 2. Median (± IQR) time in hours, grouped by type of WBV exposure, that trucks could be operated until reaching the ISO DVALs. Time limits were based on whole route exposures.

Time Limits	(n = 16) Seat 1	(n = 13) Seat 2	(n = 12) Seat 3	p-value
A(8) (hour)	6.2 [a] (2.7)	10.5 [b] (8.4)	10.3 [b] (2.2)	0.003
VDV(8) (hour)	3.3 [a] (3.1)	8.7 [b] (14.9)	8.9 [b] (6.0)	0.009

Values with different superscripts across row are significantly different

DISCUSSION

This study compared the WBV exposures and WBV attenuation performance of three seats across different road types. The results demonstrated that the WBV attenuation performance of the three seats differed and was dependent on road types. Similar to a previous study where older versions of Seat 1 and Seat 2 were tested across a non-standardized set of predominantly paved roads (Kim et al., 2015), Seat 1 also had significantly higher WBV exposure (poorer WBV attenuation performance) when compared to Seat 2. Besides validating the differential seat performance in a more controlled setting, this study also showed that there is another seat, Seat 3, which also has the potential to significantly reduce and attenuate WBV exposures. As shown in Figure 3, in the on-road paved segments, both Seat 2 and Seat 3 attenuated more floor transmitted WBV exposures compared with Seat 1.

One concern with the current comparisons may be the older age of Seat 1, but in our RCT which measured WBV exposures in new seats over a one year period, no decline in seat performance was observed (Kim et al., 2015). The other interesting result is that there was a seat by road type interaction indicating that there was no difference in seat performance in the off-road segments. This may indicate that speed plays a role in seat suspension performance, where at the higher speeds, seat suspension performance becomes more critical. At faster speeds, there is more high frequency energy content in the WBV exposures (Johnson et. al, 2012) and higher frequency content of the vibration results in much shorter seat travel. If the seat suspension is not optimized to reduce friction at the shorter travel distances, this higher frequency vibration energy can be transmitted to the driver. The results indicate suspension of Seat 1 may have greater friction and thus exposes drivers to vibration with higher frequency content, and this will subsequently be evaluated by comparing Power Spectral Densities (vibration energy content as a function of frequency) across the seats over identical road segments.

In a future study we also want to add and compare the performance of an active suspension seat in the same set of drivers, trucks and roads. Based on the prior study (Kim et al., 2015), we expect up to a 50% reduction in WBV exposures relative to the three air-suspension seats. With this reduction in WBV exposures via the active suspension seat, we anticipate the time it takes truck drivers to reach daily vibration action limits will range between 8 to16 hours. We are not advocating that truck drivers operate their trucks for such long durations, but rather the longer vehicle operation time indicates how much lower and acceptable the WBV exposures are with the active suspension seat. The results from our randomized controlled trial study indicate that lowering WBV exposures will reduce self-reported low back pain (Kim et al., 2015) and seats which reduce WBV exposures may potentially reduce other vibration related musculoskeletal disorders among truck drivers. Our results indicate that two air-suspension seats are currently available to reduce truck driver WBV exposures.

ACKNOWLEDGEMENTS

This work was financially supported by Worksafe BC and the Washington State Medical Aid and Accident Fund. The authors would like to thank Arrow Transportation Systems Inc.; Rick Vivendi, the Director of Health, Safety and the Environment; and their management, staff and truck drivers for participating in this study.

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