Determining how Long Truck Driver Whole Body Vibration Exposure Data has to be collected to Accurate Estimate Actual Daily Exposures

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Abstract

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Introduction: Exposure to Whole body Vibration (WBV) has been associated with increased prevalence of low back pain in occupational settings. Not only does exposure to WBV have a high personal cost for worker's who experience chronic pain, but it also has a high impact on the costs of workers' compensation claims. Current guidelines, the International Standard of Mechanical Vibration and Shock (ISO 2631-1) are devoid of any identifiable or concrete recommendations for the length of time needed to accurately and reliably characterize a vehicle operator's exposure to WBV. Determining and optimizing the required measurement duration period is needed to characterize a full-shift exposure for WBV exposure measurements as well as reducing the costs associated with assessing and addressing WBV-related issues.

Methods: This study used tri-axial accelerometers with a GPS logger to measure WBV in regional 58 truck drivers for 64 full-shift samples. It focused on three WBV exposure parameters: root mean square weighted acceleration (Aw), vibration dose value (VDV), and the Seat Effective Amplitude Transmissibility (SEAT) ratio. Seat exposure measurements were taken in 3 axes (X, Y, and Z). Each full-shift sample was broken into segments of differing measurement durations (minutes) from the same common data collection starting point: (5, 7.5, 10, 15, 30, 60, 120, 240, 480) Using the GPS data, WBV exposure data was also characterized on the basis of whether the vehicle was moving or not moving.

Results: The Z-axis was determined to be the predominant axis of exposure in this study. Aw exposures in the X- and Z- axes increased for the first 60 minutes. A follow up Tukey test showed that measurement durations of 30 minutes or longer in the predominant Z- axis were no different than the full-shift, 8-hour exposure measurement. This observation was supported for VDV and across the other axes. An analysis showed that the SEAT values should be based solely on WBV exposures during vehicle movement or SEAT values will likely be overestimated if based on moving and non-moving vehicle exposures.

Discussion: In this study, the Aw analysis along the Z-axis showed that shorter durations of measurement exposure (30 minutes or longer) can accurately characterize the daily full-shift exposure of regional truck drivers. The analysis of the exposure data showed that SEAT values and VDV exposures should solely be based on the WBV exposures during vehicle movement. This methodology may be employed for other operators of other vehicle types and workers in other industry sectors.

Introduction

Low back pain is a leading cause of lost productivity in the workplace (Punnett 2005). One study (Punnett 2005) estimated around 818,000 disability adjusted life years lost to incidents related to low back pain. Another study commented that the medical and indirect costs of occupational injuries in the US in 2007 was comparable to the economic burden of a major pathology such as cancer. (Leigh 2011)

Measuring and accurately determining Whole Body Vibration (WBV) exposures is crucial to understanding the potential health and economic impacts these exposures may have on the transportation industry. As one of the most impactful non-lethal conditions, occupational low back pain imposes notable "economic burden" and "lost productivity in the workplace" through its chronic disabling course. (Punnett 2005) Washington state's Labor & Industries compensation claim data revealed that 1 out of 13 truck drivers has a work-related injury resulting in a lost work time workers' compensation claim. (Rauser 2014) Employers face expenses related to claims, lost productivity, and time away from work. Employees face reduced wages, difficulty navigating the intricate insurance system, and disruptions in both their occupational and non-occupational lives.

An association between exposure to Whole Body Vibration (WBV) and occupational low back pain has been established in the literature and marks it as an impactful contributor to work-related costs. (Bovenzi 1999, 2006, Hulshof 1987, NIOSH 1997, Stewart 2003). Repetitive and/or excessive loading on the spine is one such mechanism that may explain WBV's association to occupational low back pain. (Bovenzi 1999) Horizontal displacement/torsion of the vertebral column can also increase the chances of degenerative processes, such as spondylosis deformans, which may make workers more susceptible to injuries. (ISO 2631-1). Acute traumatic back strains can lead to chronic low back pain and cause further strain on economic and human resources. Long-haul truck drivers are especially susceptible to these types of strains, as they drive for long periods that often exceed 40-hrs/week. (Johnson 2018)

Whole Body Vibration:

Whole body vibration is characterized by the energy transmission from the environment to a worker while either standing or sitting. (Johnson Ed: Levy 2017) Many workers in the transportation sector experience large vibratory energy transmission from heavy equipment vehicles such as forklifts or semi-trucks. This energy can transmit through the vehicle operator's feet or buttocks and can harm the operator's organs, affecting different organs at different frequencies. The range of frequencies that is thought to be harmful ranges between 1-100 Hz. Vertical vibrations ranging between 4-12 Hz excite and resonate through the spine and torso. Horizontal vibrations between 1-4 Hz also contribute to adverse health issues. (Johnson Ed: Levy 2017)

Addressing and/or trying to reduce WBV exposures can decrease a vehicle operator's chances for developing low back pain and can potentially expedite return to work after an occupational low back injury. Ergonomic interventions have been documented that reduce the frequency of low back pain. (Griffin 2006) The main means to address and reduce WBV exposures is through engineering controls, primarily involving seat design. (Tayyari and Smith 2003) Based on the vibrations being transmitted through the vehicle to the operator, the seat suspension design can be altered and optimized to reduce the vehicle-induced vibrations. Studies have demonstrated the success of using active suspension seats as an engineering control to reduce WBV exposure. (Blood 2011, Johnson 2018, Kim 2015, Kim 2018) Additionally, such a vibration dampening seat would also benefit truck drivers who have suffered from low back pain outside occupational exposures.

The current guidelines of exposure, the International Standard of Mechanical vibration and shock (ISO 2631-1: 1997), note that the duration of exposure measurement should be "sufficient to ensure reasonable statistical precision and…that the vibration is typical of the exposures which are being assessed." Exposure measurements are collected and analyzed in a way to be representative of the whole exposure period, a full 8-hour shift in this context. (Direction 2002/44/EC) Accelerometers are used to capture the mechanical energy that is converted into electrical energy measured as acceleration. (Griffin 2006) Exposure to vibration is measured across three main axes: X (front to back), Y (side to side), and Z (up and down) (ISO 2631-1: 1997). WBV magnitude is the highest frequency-weight acceleration in these three orthogonal axes in seated or standing positions. Also, the work pattern of the industrial vehicle is essential to determine the most accurate ways of measurement and interpretation of data (Griffin 2006). Long-haul truck drivers, the subjects of Griffin's study, have different exposures as compared to crane operators working on a construction site. For the subjects of this thesis, the dominant axis of measurement is the Z axis based on the nature of the truck, equipment and functional component of driving trucks for long hours.

There are no established recommendations for the duration of WBV exposure measurement to approximate the exposure of a full shift. Although, the European Parliament and the Council of the European Union, the legislative body of the European Union, discusses WBV and the associated daily action and exposure limit values. (Direction 2002/44/EC) The daily exposure action value standardized to an 8-hr reference period was set to be no higher 0.5 m/s^2 and 9.1 $m/s^{1.75}$ respectively. This directive also established the daily exposure limit values, standardized to an 8-hr reference period, to be no higher than 1.15 m/s^2, and the vibration dose value was set at 21 m/s^2. Few industry standards are available to manage adverse exposures to WBV. (Griffin 2006)

Currently, there is no concrete guidance in any of the current standards or literature on how long WBV exposure data has to be collected in order to estimate 8-hr daily exposures with sufficient and reasonable accuracy. The aim of this study, using regional truck drivers, is to determine how long WBV exposure data had to be collected in order to obtain sufficient and reasonable estimates of the true, 8-hr daily WBV exposures. In a large WBV exposure data set from regional truck drivers, we will compare - full-shift, 8-hr exposure assessments to exposure assessment periods of shorter duration. We want to determine whether shorter measurement durations can be used to accurately approximate the true, 8-hr daily exposures. These results could have important implications for the efficiency and accuracy of WBV exposure assessments and impact study designs and the costs associated with WBV exposure assessment.

Methods

The data was obtained from a prior study that collected seat vibration data. (Kim et al 2016) In the Kim (2016) study, full-shift whole body vibration (WBV) exposure data was collected from 105 professional truck drivers from 5 different companies in North America. The drivers were regional or line-haul drivers whose predominant duties included driving the vehicle. The truck drivers all had at least 1 year of employment with their current company. These drivers 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 prior to study participation. For this analysis all data was de-identified and contained no personal identifying information.

Whole Body Vibration Exposure Data

All of the seat-measured WBV exposure data was collected in three axes (X, Y, and Z shown below) with a focus on the two main WBV exposures parameters, defined in ISO 2631-1: 1997:

Root mean square (r.m.s.) weighted average acceleration (A_w), measured in m/s^2, is used for characterizing continuous cyclical exposures occurring over a period of time.

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

Where $a_w(t)$: instantaneous frequency-weighted acceleration at time, *t*; T: *the duration of the measurement, in seconds.*

Vibration dose value (VDV), measured in m/s$^{1.75}$, is more sensitive to impulsive vibration and captures cumulative impulsive exposures occurring a period of time :

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

VDV is a cumulative measure to capture the entire exposure to impulse vibration. To extrapolate the data to be a proxy for impulsive vibration exposures for an entire shift, VDV measurements can be normalized to an 8 hour span, signified by VDV(8) given by the following equation:

$$\text{VDV(8)} = \text{VDV} * [\frac{8\ hours*60\ seconds*60\ seconds}{seconds\ measured}]^{\frac{1}{4}} * [\frac{exposure\ duration}{measurement\ duration}]^{\frac{1}{4}}$$

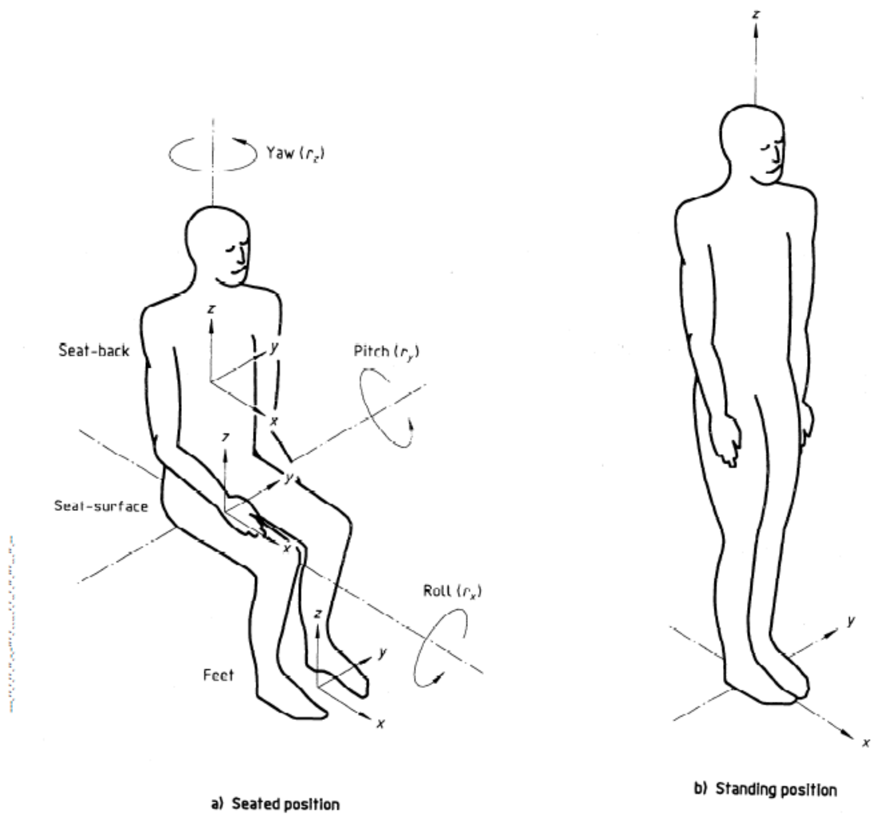


Figure 1 — Basicentric axes of the human body (ISO 2631-1)

The ISO guidelines require WBV exposure studies to establish the predominant axis of exposure for each specific scenario. In our study of regional truck drivers, the Z-axis was established to be the predominant axis of exposure. This is due to the functional nature of the job of a truck driver which includes long steady drives over 30 miles on a paved highway compared to other operations like the jarring motion of a crane. To account for health contributions in the X and Y axes, the ISO 2631-1 standard requires a multiplier of 1.4 be applied to the X and Y axes exposure measures measurements along these respective axes.

The Seat Effective Amplitude Transmissibility (SEAT) value was also calculated. The SEAT value is the WBV exposure measurements (on the predominant Z-axis) at the seat divided by the WBV exposure measurements of the floor. This ratio serves as a proxy for the efficacy of the seat to absorb and indicates how much of the floor-measured WBV exposure is transmitted through the seat to the driver. A ratio value lower than 1 suggests that the WBV exposure at the seat is reduced compared to WBV vibration at the floor. We also aim to determine whether any bias is present when characterizing a truck driver's seat performance (SEAT) over all truck operations (Moving + Nonmoving) or exclusively when the truck is moving (Moving only), specifically along the predominant Z-axis.

Data Collection

Per the International Organization for Standardization (ISO) 2631-1 WBV standards (2007), a tri-axial seat-pad accelerometer (Model 356B40; PCB Piezotronis; Depew, NY, USA) was positioned on the vehicle operator's seat to measure the WBV parameters of focus at 1280 Hz. Another accelerometer was also placed on the floor of the truck beneath the seat. Raw un-weighted acceleration data at 1280 Hz was collected for the full work shift (8-15h) by a four (Model DA-20; Rion; Tokyo Japan) or eight channel data recorder (Model DA-40; Rion; Tokyo, Japan). Additionally, a GPS logger (Model DG-100; GlobalSat; Chino, CA, USA) recorded vehicle speed at 1 Hz.

From the original data set of 105 measurements, since the study goal was to determine how long WBV exposure data would have to be collected to accurately estimate daily 8-hr exposures, truck drivers had to operate their truck 8 hours or more to be included in this data analyses. This reduced our sample size to 64 full-shift, 8-hour samples of WBV exposures from 58 distinct truck drivers. To ensure data quality and erroneous data associated with equipment or instrumentation problems the raw WBV data was analyzed second-by-second, and peak, mean and SD values were calculated within 1 s epochs. We excluded raw WBV exposure data that had a peak, mean or SD value above 40 m/s^2, +/- 1.0 m/s^2 or 3.2 m/s^2 within these 1 s epochs and calculated summary measures from the remaining data. Less than 0.5% of the collected data was removed in this manner. Factors that likely contributed to measurements outside these ranges included the superimposition of signal noise from the electronic and communication equipment in the truck cab on the data, temporary strain of connector shorts, or transient shocks overloading the accelerometers.

Positioning of Accelerometers (Kim 2016)

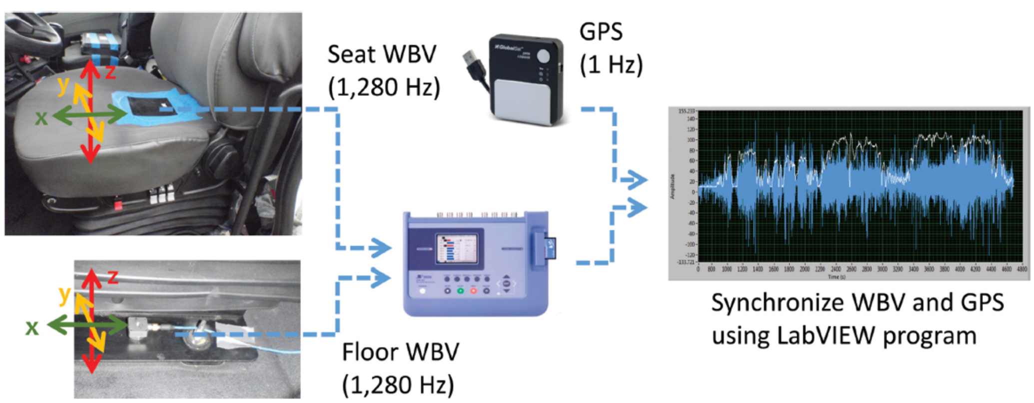


Figure 1 Data acquisition system. Tri-axial accelerometer axes: fore-aft (x), lateral (y), and vertical (z).

Data Processing

The data were analyzed using the two WBV exposure measures outlined in ISO 1631-1 1997, A_w and VDV:

A_w in X axis of seat, Y axis of seat, Z axis of seat and Z axis of the floor.

VDV in X axis of seat, Y axis of seat, Z axis of seat and Z axis of the floor.

Using the GPS data, the WBV exposure data for each parameter was separated into three segments: Moving, Nonmoving, Moving + Nonmoving. Moving data consisted of periods in which the truck was moving. It was Data was categorized as moving if the truck speed was greater than 1 km/hr with no idle periods longer than 60 seconds. Defined by the speed of the truck being less than 1 km/hr for periods of 60 seconds or longer, nonmoving data was all the other data that did not meet the criteria for vehicle movement and can be considered comparable to the truck being idle. Consequently, the Moving + Nonmoving segment was the inclusion of both groups and represents the complete data set

Based on truck speed, each exposure measurement began and ended at the truck terminal, this resulted in 64 distinct full shifts WBV exposure measurements over 480 minutes (8-hr) in duration. A LabView Program was used to cut and process each distinct full shift sample into multiple samples between 5 minutes and 8 hours of exposure (5; 7.5; 10; 15; 30; 60; 120; 240; 480). The 480 minute measurement was used at the "true" full-shift, 8 hour daily exposure .

Each exposure measure was analyzed by the type of WBV exposure data (moving, nonmoving and moving + nonmoving) and compared over the nine different time periods.

A repeated measures analysis of variance (RANOVA) was applied to the data for each exposure measure (A_w, VDV), type of WBV exposure data (moving, nonmoving and moving + nonmoving), and duration (5; 7.5; 10; 15; 30; 60; 120; 240; 480minutes). A Tukey HSD test followed the RANOVA analysis to determine for statistical significance between the independent variables.

Results

Predominant Axis of Exposure

As Shown in Figure 1, the 8-hr, full-shift, A(8) WBV exposures collected across all three axes (x axis, y axis, z axis) revealed that the z axis seat WBV exposures was higher compared to the x and y axes, indicating the z axis was the predominant axis of exposure.

Figure 1: Comparison of mean (SE) A(8) WBV exposures by axis (n=64).

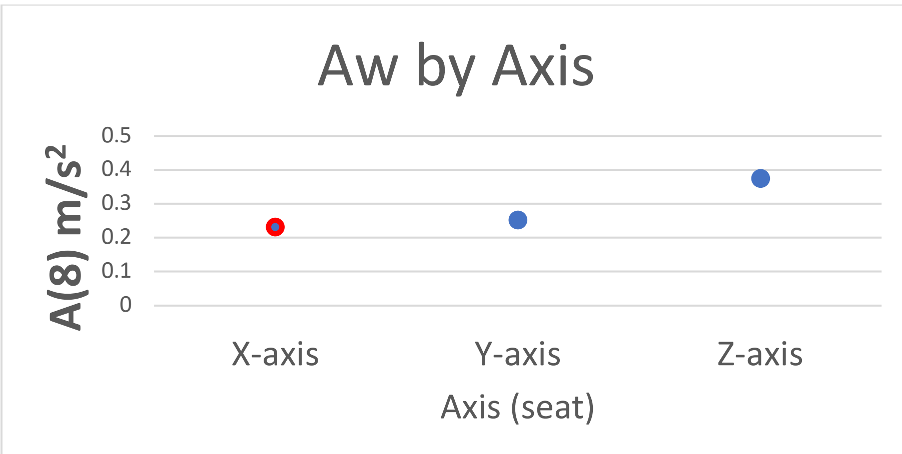


Figure 2a: Comparison of the A(8) WBV exposures in the X- and Z- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).

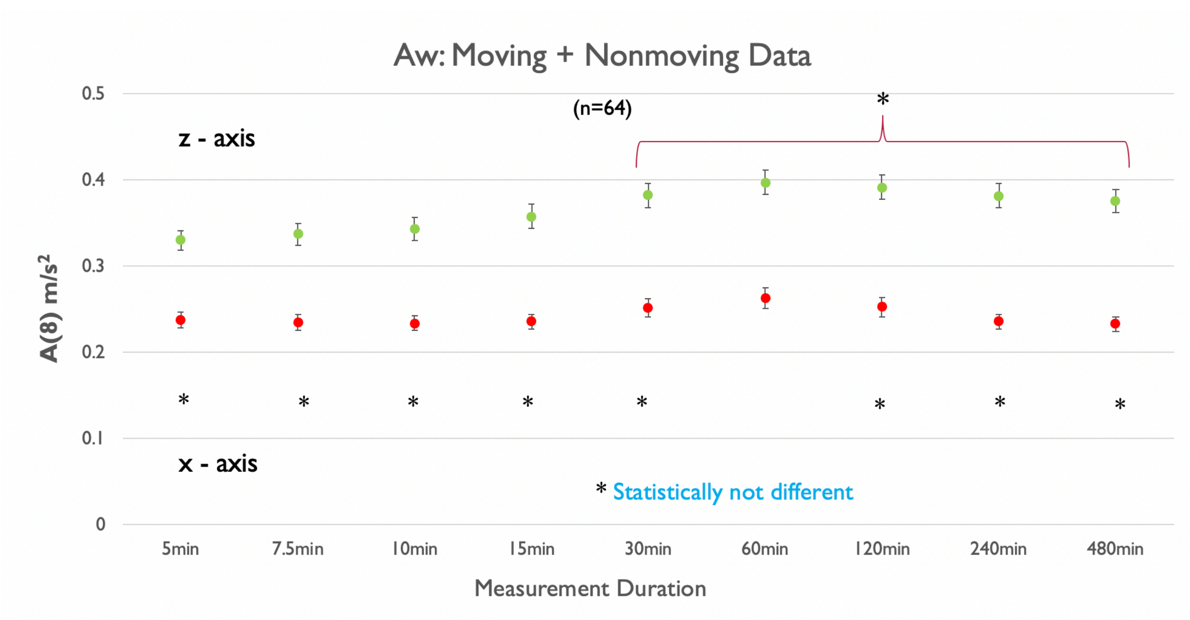
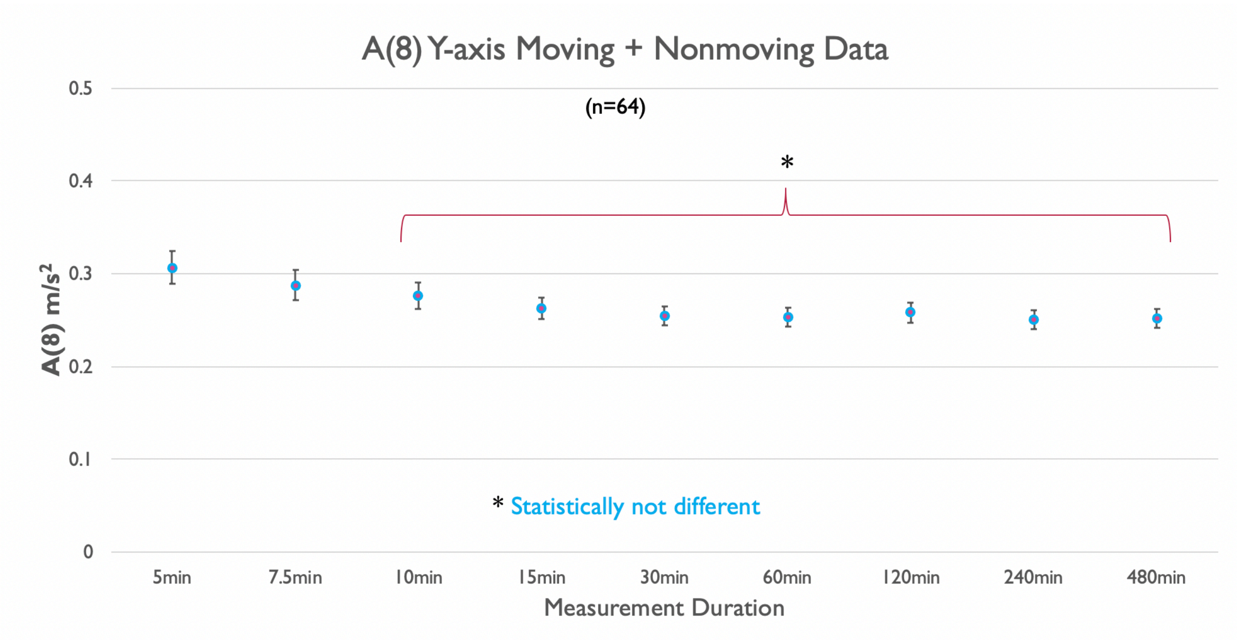
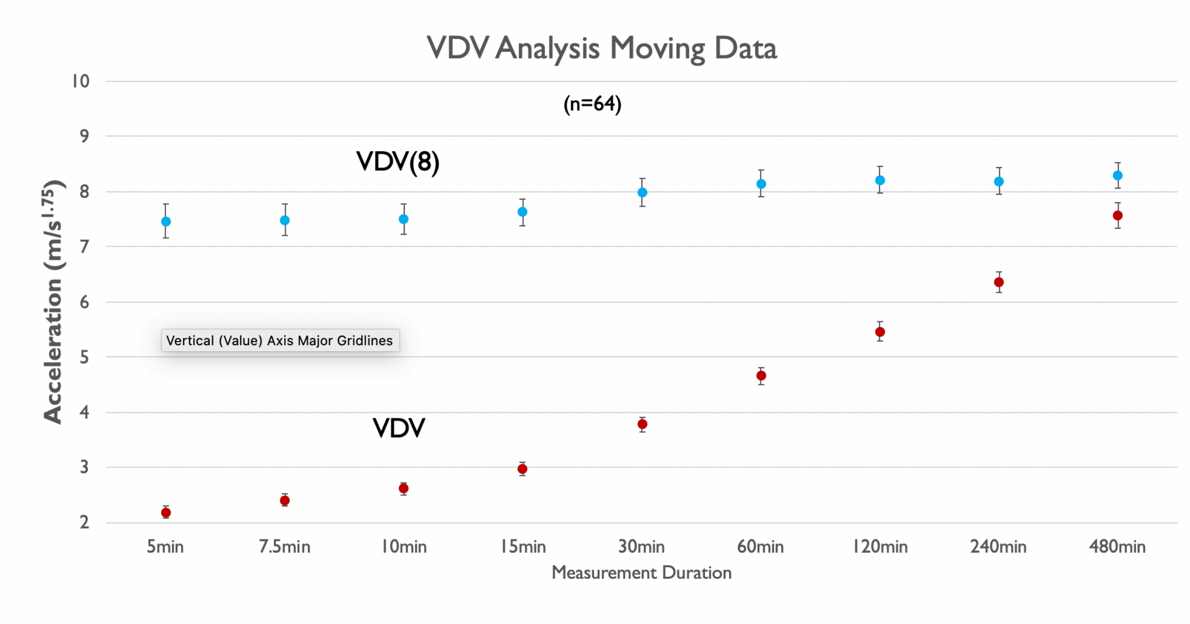


Figure 2b: Comparison of the A(8) WBV exposures in the Y- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).



As shown in Figure 2a and 2b, Average Weighted Vibration [A(8)] WBV exposure data, normalized to 8 hours of truck operation, were plotted as a function of measurement duration (5 mins to a full shift of 480 minutes). As shown in Figure 2a, the X- and Z- axis WBV exposures increased and stabilized after 60 minutes of measurement. For the predominant Z-axis exposures, the Tukey HSD follow-up test indicated that measurements between 30 to 240 minutes would accurately approximate the true, full-shift, 8-hr exposures (480 minute measurements). For the X-axis, all but the 60 minute measurement would accurately approximate the true, full-shift, 8-hr exposures. In contrast to the Z- and X-axes, as shown in Figure 2b, the Y-axis WBV exposures had an opposite pattern where the 60 minute measurement corresponded with the lowest exposure. For the y-axis, measurements between 10 to 240 minutes would accurately approximate the true, full-shift, 8-hr exposures.

Figure 3: Comparison of VDV and VDV(8) WBV exposures by measurement duration (n = 64).



The pattern for VDV is explained by the cumulative nature of the formula used to measure and characterize VDV. As the measurement duration increases, the impulsive WBV exposures are added to one-another and the cumulative measurement and the exposures will rise over time. Figure 3 compares VDV and VDV(8) based on the Moving data. As can be seen, VDV without normalization is an inadequate measure of impulse WBV exposures over short term periods and normalization to VDV(8) is essential.

Figure 4a: Comparison of VDV(8) WBV exposures in the X- and Z- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).

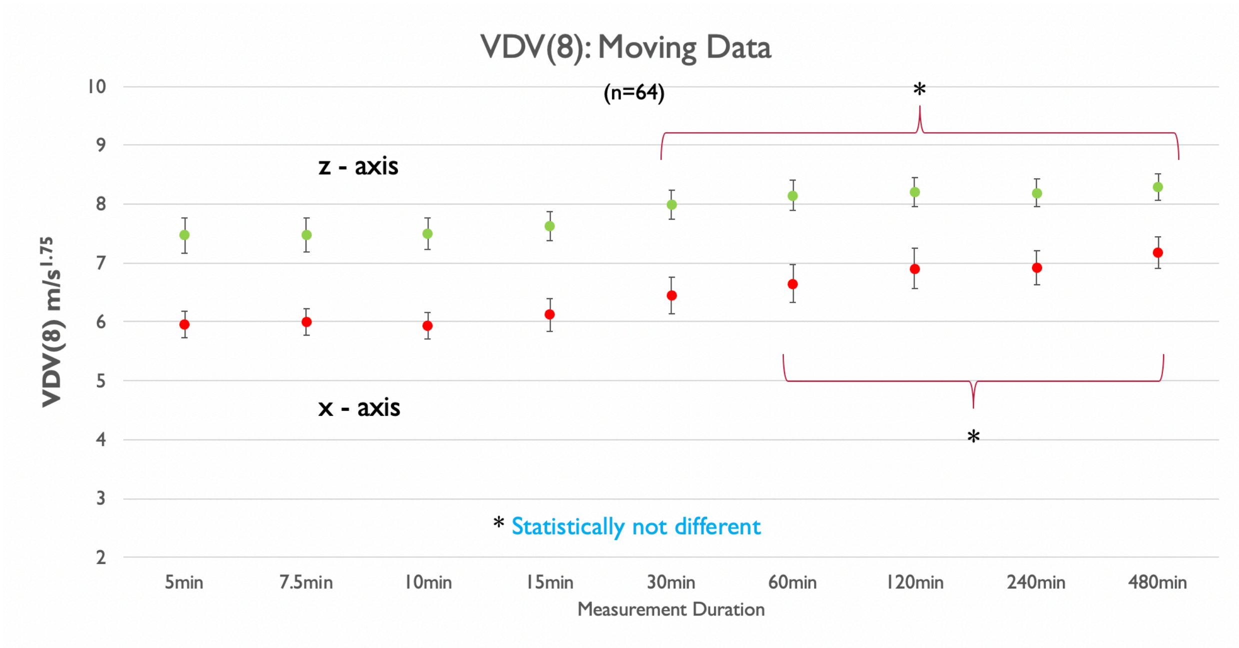


Figure 4b: Comparison of VDV(8) WBV exposures in the Y- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).

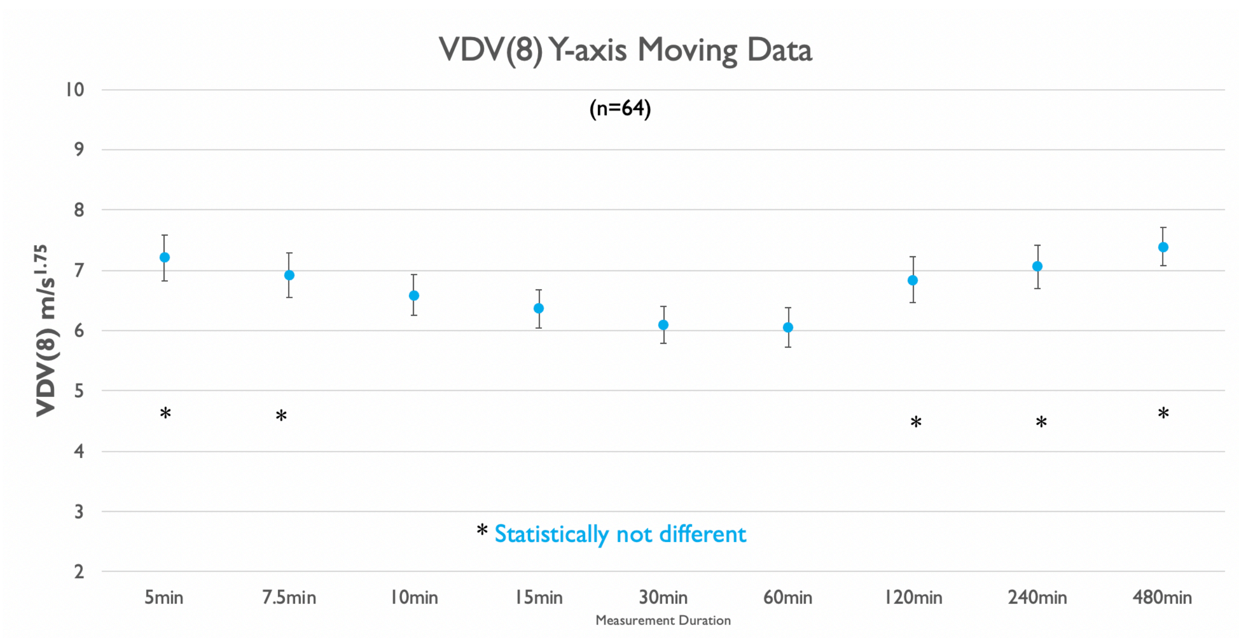


Figure 4 shows the X-, Y-, and Z- axis seat-measured Vibration Dose Value WBV exposures, calculated from the moving data, normalized to 8 hours of truck operation [VDV(8)].For the predominant Z-axis, similar to the A(8), WBV exposures between 30 to 240 minutes would accurately approximate the true, full-shift, 8-hr exposures. For the X-axis, measurements between 60 to 240 minutes would accurately approximate the true, full-shift, 8-hr exposures.

Figure 5: Comparison of SEAT values by the type of WBV exposure data (n=64)

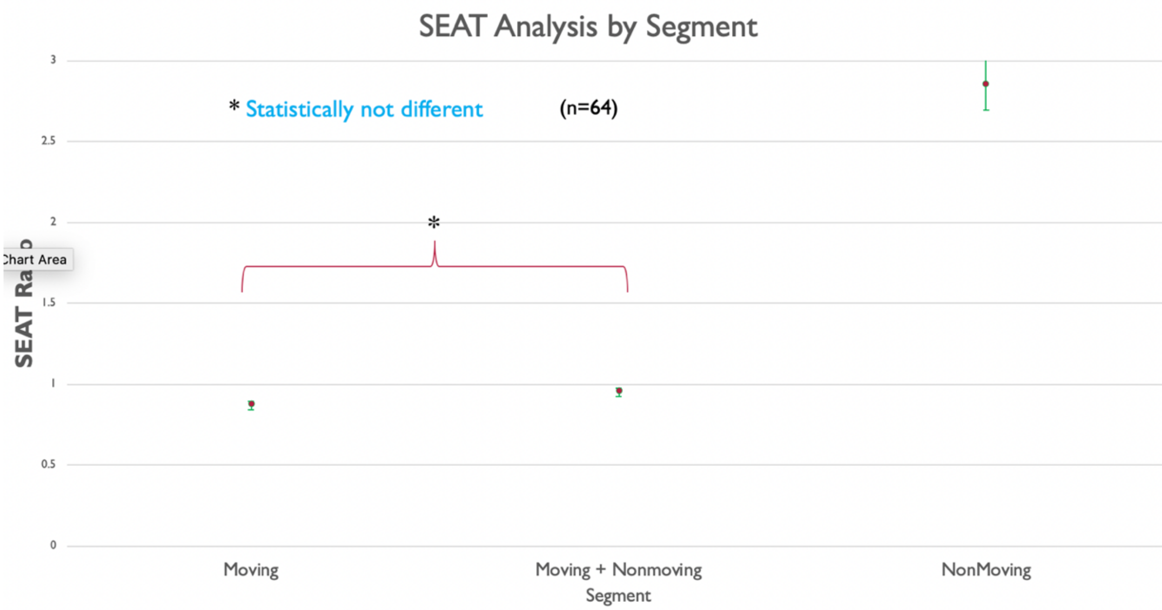
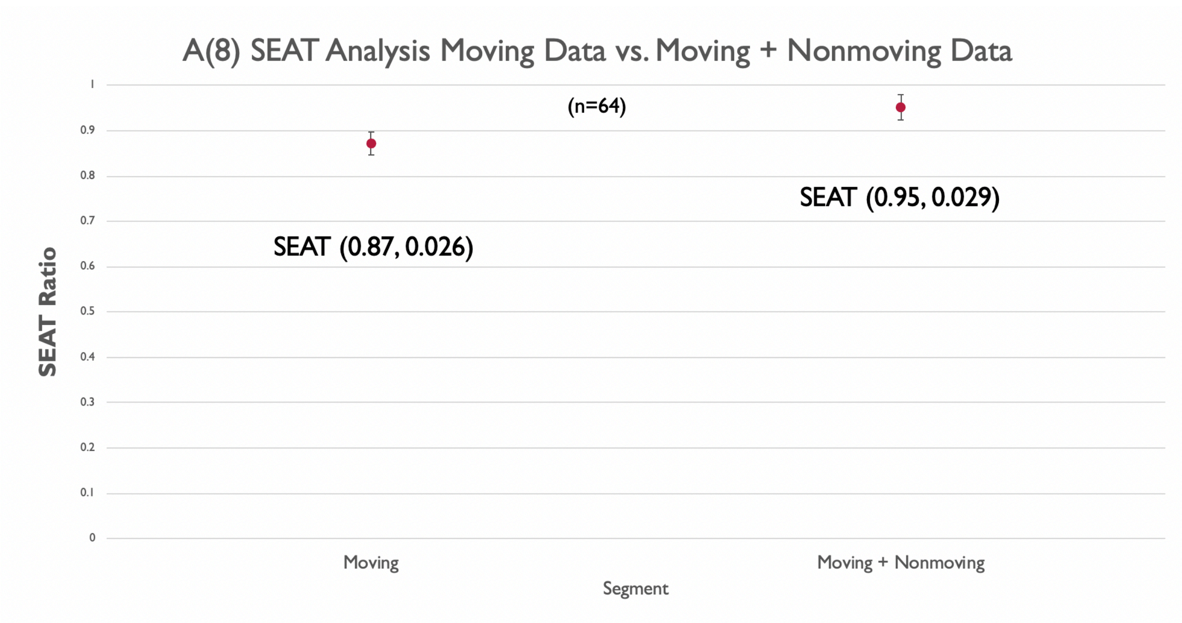


Figure 6: Comparison of SEAT values between the Moving vs Moving + Nonmoving WBV exposure data (n=64).



The A(8) SEAT values, compared by the type of WBV exposure data, showed that SEAT value based on the NonMoving data was significantly higher than the SEAT values based on the Moving + NonMoving data and the Moving data. (Figure 6) In addition, the A(8) SEAT values were higher ($p < 0.0001$) in the Moving + Nonmoving group (95%) than the Moving group (87%) alone. (Figure 7)

Discussion

The higher WBV exposures in the Z axis, demonstrated in Figure 1, indicated that the Z axis (up and down) was the dominant axis of exposure in the regional truck drivers assed in this study. (ISO 2631-1) Although, vector sum WBV exposure: a measure that combines exposure measurement along all axes (x, y, and z) was proposed to be more relevant because the predominant axis approach could underestimate WBV exposure. (Jonsson 2014)

The A(8) parameter on the Z-axis demonstrated that shorter durations of measurement were comparable to the "gold standard" duration of 480 minutes. (Figure 2a) The Tukey test revealed that measurement durations as short as 30 were equivalent to the true, full-shift, 8-hr measurements (480 minutes). This suggests that shorter periods of A(8) exposure measurement than full-day 480 minutes can accurately characterize the daily full-shift A(8) exposure of regional truck drivers. Unlike this study, other studies that have looked at similar WBV exposures in truck drivers (Blood 2011, Blood 2010, Kim 2015, Johnson 2018, Kim 2018), but these studies did not include recommendations for sample sizes, both for the number of samples needed and for the data sample duration to obtain reliable exposure estimates. Shorter, valid WBV exposure assessments of 30 minutes, rather than full-shift 480 minute measurements, can lessen the demand of resources needed to assess WBV exposure and may affect the downstream effects of addressing occupational worker's compensation claims.

As shown in Figure 2a, the increase in the z-axis WBV exposures up to 60 minutes was likely due to the average speed of the truck increasing after it left the truck terminal. The decrease in WBV exposures after 60 minutes was likely due to a stop or stops on the route where the truck was not moving. Based on the analysis, Z-axis WBV exposure measurements of 30 minutes or longer would accurately estimate full-shift, 8-hour WBV exposures. Many factors during the initial 30 minutes of a drive such as road condition and number of stops and turns can vary widely from one full-shift exposure to another. The inverse pattern seen in the Y-axis (Figure 2b) was thought to be the result of the initial jarring motion caused by hitching the trailer to the truck cab. The initial high lateral or Y-axis exposures that resulted from connecting the trailer were de-weighted as the measurement duration increased.

This study supports the practice of using VDV(8), normalized to a full 8-hr shift, to evaluate impulsive vibration exposures. (Griffin 2006) Across all measurement durations, normalized, VDV(8) exposures were higher compared to the non-normalized VDV exposures. (Figure 3) The graphs do not converge until the 8 hour mark where the measurement duration for VDV is equivalent to the 8 hour duration that all VDV(8) measures are normalized to.

The analysis of the predominant, Z-axis VDV(8) exposures paralleled the results of the Z-axis, A(8) exposures, that measurement of 30 minutes or longer would accurately estimate full-shift, 8-hour WBV exposures.

The Seat Effective Amplitude Transmissibility (SEAT) data should be analyzed within the context of “Moving” data exclusively because the “Nonmoving” component of the data significantly overestimated the WBV exposures. (Figure 5) A subsequent analysis of A(8) SEAT ratios revealed that the Moving + Nonmoving segment values were nearly 10% higher than values within Moving data alone (87%). (Figure 6) These “Nonmoving” segments of WBV exposure collection include external artifacts such as the vibration when the truck is idle and the driver is not on the seat or when the driver sits down to continue to drive. The VDV(8) parameter should also be analyzed within the context of “Moving” data exclusively for similar reasons. Pairing GPS data with the exposure WBV data allowed this study to determine when the truck was moving and functioning. Several studies have looked at GPS with WBV exposure, but none have commented on the characteristics of moving vs nonmoving data to date. (Blood 2010, Blood 2011, Johnson 2018, Jonsson 2014, Kim 2015, Kim 2018, Thamsuwan 2013) With the dramatic increase of WBV measurements due to jarring movements, we propose that “Nonmoving” data should not be considered with SEAT or VDV(8) exposure assessments.

Strengths and limitations of the Study

The strength of this study includes its robust data set with 64 full-shift exposures to truck drivers with corresponding GPS data. Currently, there are no recommended guidelines for duration of WBV exposure assessment. Data from this study can be an important step to help establish guidelines for truck driver WBV assessment. An exposure measurement duration that is shorter than a full-shift, 8-hr exposure lessen a the costs associated with the exposure assessment and implementation. Additionally, this data is comprised of actual, field-based exposures and should be reliable for determining valid field-based, exposure measurement durations.

This assessment also paired WBV exposure with GPS data to strengthen the data, similar to other studies. (Blood 2010, Blood 2011, Johnson 2018, Jonsson 2014, Kim 2015, Kim 2018, Thamsuwan 2013) With this, we were able to evaluate the differences between segments of Moving data, Nonmoving data, and combined Moving + Nonmoving data. This ability was crucial to allow us to determine the appropriate data that is needed to analyze impulse WBV measurement, VDV(8), and SEAT ratios.

One main weakness is the applicability of these results and conclusions outside of the context of regional truck drivers who operate along paved roadways. Different scenarios of occupational WBV exposure vary widely and depend on the vehicle, road surfaces, location, etc. The results of this study yielded small standard errors throughout the different analysis.

These methods can be applied to demonstrate the relationship of the data collected stratified into differing time segments. Going forward, it is recommended the established relationships between time as a variable, axis as a variable and parameter as a variable should be preserved. Further studies could apply the methodology of this study, including pairing exposures with GPS, to determine valid Moving + Nonmoving data for Aw and Moving data only for VDV(8). Possible applications include studying different vehicles and studying truck driving roles such as delivery truck drivers and less than truckload drivers. Another step could involve designing a stronger study design including cohort studies with a prospective timeline. (Johnson 2018, Kim 2018)

As this study could not determine causality, more studies can take WBV exposure measurements and correlate that data with reliable clinical indicators. A couple studies found statistical significance after an engineering seat intervention but did not find significance in the clinical indicators. (Johnson 2018, Kim 2018) There is still much work to be done to determine which clinical indicators are most relevant and whether a causal relationship exists.

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Appendix 1

Figure 1: Comparison of means (SE) A(8) WBV exposures by axis (n=64).

	Mean	**Std Err(Value)**
X-axis	0.23220284	0.00782282
Y-axis	0.25172503	0.00998046
Z-axis	0.37485848	0.01348524

Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures.

Figure 2a: Comparison of the A(8) WBV exposures in the X- and Z- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).

Measurement Duration	X-axis	**SE**	Tukey HSD	**Z-axis**	**SE**	Tukey HSD
5min	0.237244	0.009409	*	0.329469	0.011671	
7.5min	0.233931	0.009213	*	0.336768	0.012588	
10min	0.233411	0.00882	*	0.34272	0.012887	
15min	0.235166	0.008892	*	0.356947	0.014126	*
30min	0.251366	0.010597	*	0.381503	0.01376	*
60min	0.262394	0.01134		0.396751	0.013867	*
120min	0.252376	0.011445	*	0.39121	0.014238	*
240min	0.23551	0.00826	*	0.381093	0.013895	*

480min	0.232203	0.007823	*	0.374858	0.013485	*

Figure 2b: Comparison of the A(8) WBV exposures in the Y- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).

Measurement Duration	**Y-axis**	**SE**	Tukey HSD
5min	0.30661219	0.01742659	
7.5min	0.2877488	0.01591854	
10min	0.27625908	0.01413813	*
15min	0.26223359	0.01170738	*
30min	0.25468341	0.01054375	*
60min	0.25377452	0.01028548	*
120min	0.25824172	0.01077874	*
240min	0.25071667	0.01032426	*
480min	0.25172503	0.00998046	*

Figure 3: Comparison of VDV and VDV(8) WBV exposures by measurement duration (n = 64).

Measurement Duration	**VDV**	**SE**	**VDV(8)**	**SE**
5min	2.184073	0.104079	7.468827	0.304753
7.5min	2.40238	0.110184	7.484054	0.288417
10min	2.606027	0.11399	7.503164	0.265801
15min	2.974412	0.117444	7.629425	0.246638
30min	3.778731	0.135723	7.983194	0.247838
60min	4.655967	0.149418	8.151139	0.251545

120min	5.466566	0.171842	8.211768	0.245657
240min	6.360719	0.190707	8.192178	0.238322
480min	7.569063	0.223906	8.290576	0.231613

Figure 4: Comparison of VDV(8) WBV exposures in the X-,Y-, and Z- axis by measurement duration. Asterisks indicate the measurement durations that are not significantly different from the 480 minute, full-shift, 8-hr exposures (n=64).

Measurement Duration	X-axis	**Std Err(Value)**	**Tukey HSD Test**	**Z-axis**	**Std Err(Value)**	**Tukey HSD Test**
5min	5.95931	0.231892		7.468827	0.304753	
7.5min	6.005803	0.221963		7.484054	0.288417	
10min	5.937078	0.219809		7.503164	0.265801	
15min	6.119719	0.27092		7.629425	0.246638	
30min	6.447052	0.317116		7.983194	0.247838	*
60min	6.646333	0.322031	*	8.151139	0.251545	*
120min	6.90633	0.33847	*	8.211768	0.245657	*
240min	6.915522	0.292504	*	8.192178	0.238322	*
480min	7.176159	0.275316	*	8.290576	0.231613	*

Measurement Duration	**Y-axis**	**Std Err(Value)**	**Tukey HSD Test**
5min	7.210254	0.379197	*
7.5min	6.915206	0.369893	*
10min	6.585894	0.340049	
15min	6.36476	0.312544	
30min	6.094496	0.312986	

60min	6.059188	0.323417	
120min	6.842469	0.38111	*
240min	7.066661	0.360301	*
480min	7.39093	0.319673	*

Figure 5: Comparison of SEAT values by the type of WBV exposure data (n=64). Asterisks indicate the data groups that are not significantly different.

Segment	SEAT Mean	Std Err(zSEAT)	Tukey HSD Test
Moving	0.87156078	0.02554047	*
Moving + Nonmoving	0.95115321	0.02863802	*
NonMoving	2.84962565	0.15372305	

Figure 6: Comparison of SEAT values between the Moving vs Moving + Nonmoving WBV exposure data (n=64).

Segment	zSEAT	SE
Moving	0.871561	0.02554
Moving + Nonmoving	0.951153	0.028638