Analysis of an Intervention to Reduce Truck Drivers' Exposure to Whole-Body Vibration

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Abstract

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Introduction. The high prevalence of low back pain in drivers of commercial motor vehicles is well-documented. A number of interventions to reduce low back pain in commercial motor vehicle operators have focused on reducing exposures to whole-body vibration (WBV).

Objective. An intervention to be evaluated for the trucking industry is an air-filled ballistic seat pad designed to reduce exposure to WBV. The effectiveness of the seat pad in semi-trucks has not yet been established. Results from a previous pilot study involving 12-ton and 16-ton vibratory rollers used by Seattle Public Utility drivers suggest that the seat pad is not effective at very low speeds (1-3 mph).

Methods. The current study measures, characterizes and compares WBV exposures in nine truck drivers who operated their trucks over the same roads. WBV exposures were compared between their existing air-suspension seat and the air-filled ballistic seat pad which sat on top of their existing seat. This study uses a Wilcoxon signed rank test to compare the seat pad's effectiveness in reducing WBV exposures relative to their existing air-suspension seat.

Results. Overall, the truck drivers' vibration exposures were above daily vibration action values set by the International Standards Organization (ISO) and the air-filled ballistic seat pad did not significantly reduce WBV exposure relative to the WBV exposures experienced with their existing air-suspension seat.

Conclusions. In the semi-trucks evaluated in this study, the air-filled ballistic seat pad was not effective in reducing WBV exposures. The seat pad has been shown to be effective in reducing WBV exposures in public transportation buses and cars. The answer for why the air-filled seat pads were not effective in semi-trucks may lie in a future analysis of the power spectral densities, which shows the vibration exposures as a function of frequency. Buses and cars produce more high frequency vibration energy, and the air-filled seat pad has been shown to be effective in these vehicles when travelling at moderate to high speeds. Trucks may produce less high frequency vibration energy, and this may have diminished the air-filled seat pad's effectiveness in the semi-truck evaluated in this study.

Disclaimer: The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Army, Department of the Navy, Department of Defense, or the United States Government. I am a military service member. This work was prepared as part of my official duties. Title 17, USC, §105 provides that 'Copyright protection under this title is not available for any work of the U.S. Government.' Title 17, USC, §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person's official duties. The study protocol was approved by the University of Washington Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects. The images in this presentation are public domain graphics and do not represent any person in this presentation.

Figure 1. Whole-Body Vibration Exposure Intervention: A Ballistic Air-Filled Seat Pad

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I also wish to thank other faculty members from the Department of Environmental and Occupational Health Sciences, including Debra Cherry, MD, MS; Joel Kaufman, MD, MPH; and June Spector, MD, MPH.

Dedication

I dedicate this work to my family, including my wife, Amie; my daughter, Katie; my son, Brady; my parents, Jim and Ev; and my in-laws, Rob and Marcia. Without their love, support, and sacrifice, I could not have completed this thesis.

My home office.

I also dedicate this work to the truck drivers of North America, whose own work goes largely unnoticed.

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Introduction

Low back pain is the most common musculoskeletal complaint affecting the labor force. 37% of all workers' low back pain has been attributed to occupational exposures (27, 41, 45). Twenty percent of workers' compensation claims and up to 45% of compensation costs are due to work-related back injuries (3, 4, 50). While lost work days and lost work productivity add to the costs to employers, the financial impact of lost wages upon the individual worker can be particularly severe.

The mental and physical toll on the worker is substantial, as well. Low back pain symptoms include chronic pain, radiation of pain distally, lower extremity numbness and tingling, distracted driving, disrupted sleep, and even depression. Clinical signs include localized tenderness to palpation and loss of touch sensation in the lower extremities. Imaging studies may reveal degenerative changes of the lumbar spine, but pain may be present in the absence of degenerative changes (53).

The high prevalence of low back pain—about 60%—in drivers of commercial motor vehicles, is well-documented (4, 5, 19, 26, 30, 31, 34, 42, 43, 46, 47). Commercial vehicle operators change jobs and some leave the occupation altogether, often for medical reasons, so the extent of the problem may be underestimated, a phenomenon known as the healthy worker effect.

Whole-body vibration (WBV) has been shown to be an important risk factor for low back pain, independent of other risk factors (15,16, 39, 42-44). Vertical moments associated with driving, from jarring bumps, large potholes, and off-road conditions, appear to impact the spine the most, in a dose-response pattern (55,56).

Provided sufficient time and intensity, WBV's cumulative impact upon the lumbar spine is analogous to sound waves breaking a wine glass. Just as sound waves can stress the glass to its breaking point, WBV can stress the lumbar spine, due to the phenomenon of resonance. Lumbar vertebrae are compressed, intervertebral discs bulge, protrude, herniate, or rupture, and the associated dorsal roots of the spinal nerves are pinched in what can often be a painful, debilitating cascade of events.

Though regulatory standards for WBV have been proposed, they are not currently enforced here in the United States. The European Union, however, has codified (EU 2002/44/EC) a standard to protect its labor force, ISO 2631-1 (1997). It utilizes an orthogonal coordinate system, depicted in a seated operator, including the x-axis (fore-and-aft), y-axis (side-to-side), and z-axis (up-and-down).

Accelerometers measure tri-axial vibration in meters per second squared (m/s^2). By convention, values are often expressed in terms of root-mean-square (r.m.s), vice peak acceleration. WBV measures, associated units, reference standard, and equations are provided below (see Table 1). A(8) is a continuous, cumulative measure of vibration time-weighted over eight hours. VDV(8) is a continuous, cumulative measure of vibration time-weighted over eight hours, as well. However, because it weighs impulse, or transient shock, acceleration more heavily, it is thought to more accurately depict the full extent of vibration exposure (38).

Table 1. Whole-Body Vibration Measures, Reference Standards, and Equations

Description	Unit	Standard	Equation
Root mean square of the instantaneous frequency-weighted acceleration.	m/s^2	ISO 2631-1	$A_w = \left[\frac{1}{T} \int_0^T a_w^2(t)dt \right]^{\frac{1}{2}}$
8-h equivalent acceleration	m/s^2	ISO 2631-1	$A(8)=Aw*(480/T)^{1/2}$
Cumulative impulsive vibration exposure	m/s$^{1.75}$	ISO 2631-5	$VDV = \left\{ \int_0^T [a_w(t)]^4 dt \right\}^{\frac{1}{4}}$

Where:

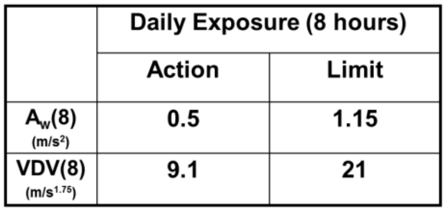
$a_w(t)$ = the weighted acceleration as a function of time measured in m/s^2
T = the duration of the measurement in seconds (37,38)

VDV is the vibration dose value in $m/s^{1.75}$
a(t) is the frequency weighted acceleration in m/s^2
T is the total measurement period in seconds (38)

Over time, the adverse health effects from vibration exposure involving multiple shocks to the lumbar spine predominate. To better protect workers, International Organization for Standardization (ISO) 2631-5 (2004) addresses these concerns. This update to the previous standard uses a biomechanical model to describe a linear relationship between peak acceleration and spinal compression due to transient shocks. The lumbar spine was found to be more susceptible to single shocks than continuous vibration (58).

Associated action values, requiring action to reduce the worker's exposure, and limit values, requiring removal of the worker from the exposure altogether in order to reduce the risk of moderate to severe adverse health effects, are provided in Table 2 (37,38):

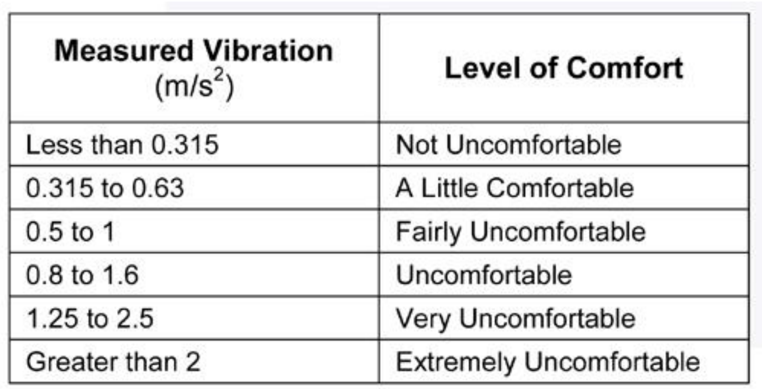
Table 2. European Union Daily Exposure Action and Limit Values



	Daily Exposure (8 hours)	
	Action	Limit
$A_w(8)$ (m/s^2)	0.5	1.15
VDV(8) ($m/s^{1.75}$)	9.1	21

For a qualitative perspective of what WBV exposures approaching or exceeding these action and limit values might mean to drivers, subjective assessments attributed to typical WBV ranges are provided in Table 3 below (37). Based upon this table, it is apparent that vibration levels exceeding the European Union daily vibration action value are associated with at least “fairly uncomfortable” levels of comfort. On a long-term basis, such levels pose serious risk of moderate to severe adverse health effects to truck drivers, including debilitating low back pain.

Table 3. Whole-Body Vibration Ranges and Associated Levels of Comfort

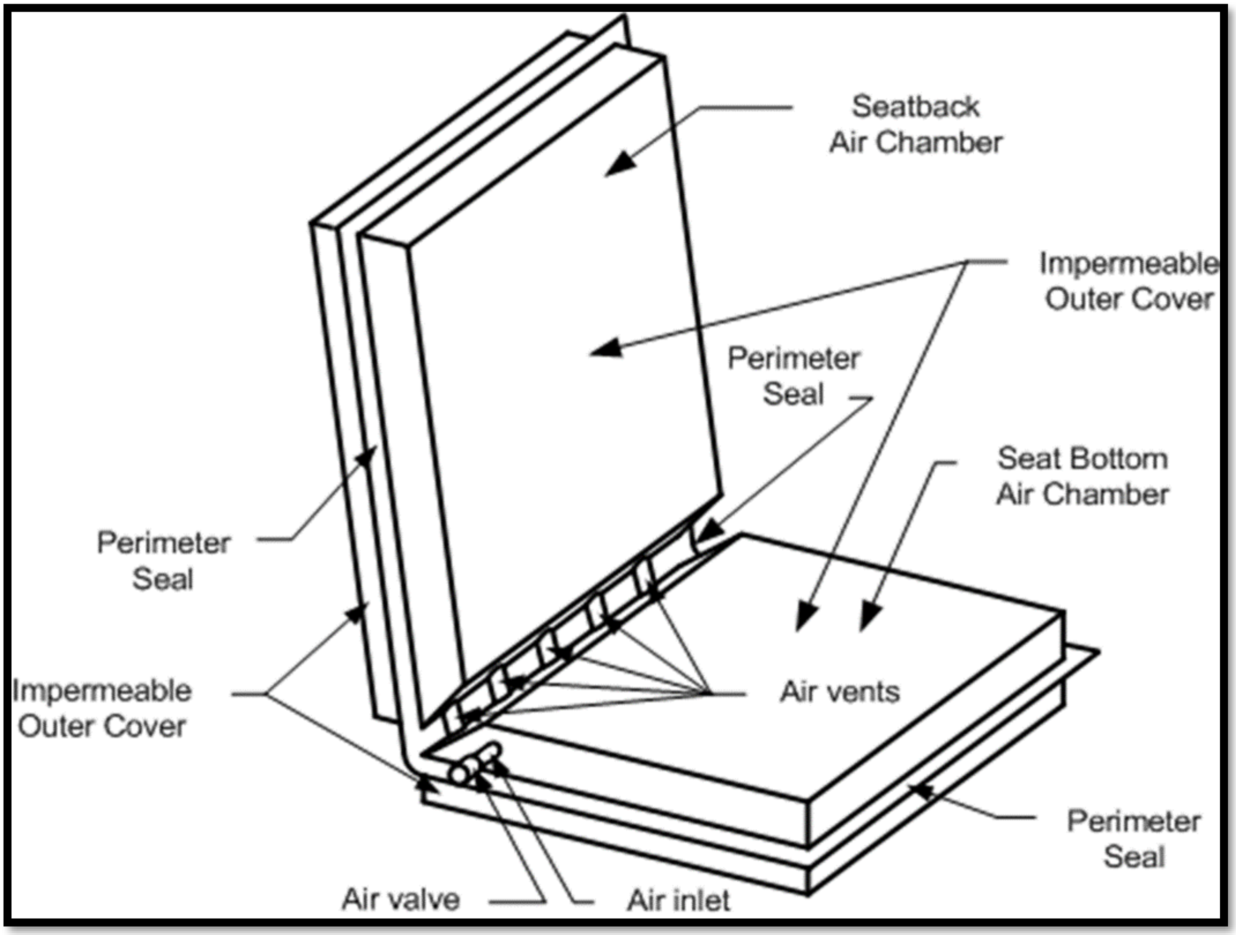


Measured Vibration (m/s^2)	Level of Comfort
Less than 0.315	Not Uncomfortable
0.315 to 0.63	A Little Comfortable
0.5 to 1	Fairly Uncomfortable
0.8 to 1.6	Uncomfortable
1.25 to 2.5	Very Uncomfortable
Greater than 2	Extremely Uncomfortable

Due to the sheer number of commercial motor vehicle operators, the high prevalence of low back pain, and its associated high costs, a number of interventions have attempted to reduce exposures to WBV, with mixed results. A new intervention to be evaluated is an air-filled ballistic seat pad designed to reduce WBV exposure (Figure 1). It presents the possibility of a cheaper alternative to the high cost of active air-suspension seats, particularly if it effectively attenuates truck drivers' exposure to WBV. However, the effectiveness of the seat pad in semi-trucks has not yet been established. This study investigated the effectiveness of the seat pad by measuring both steady state, A(8), and transient shock or impulse vibrations, VDV(8).

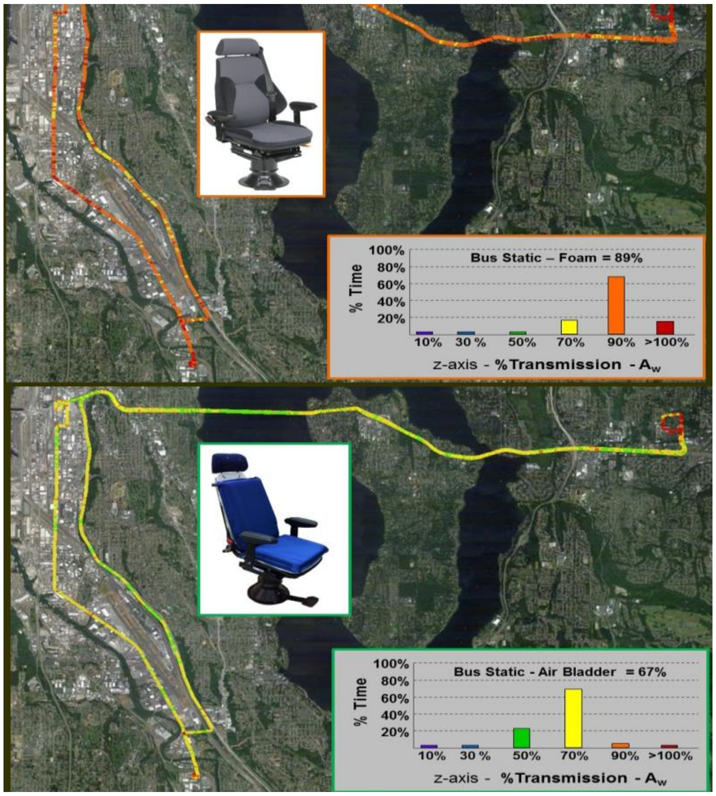
The device is engineered to diminish the energy directly impacting the user's lumbar spine. The seat pad redirects vertical moments associated with WBV horizontally, away from the lumbar spine. The transformed horizontal moments propel air through five vents between the seat cushion and the seat back (see Figure 2).

Figure 2. A Diagram of the Ballistic Air-filled Seat Pad



A previous University of Washington study of the effectiveness of the seat pad in attenuating 13 King County Metro Transit bus drivers' WBV exposure is compelling. The study involved completely replacing the stock foam seat with the ballistic air-filled seat pad. Results showed a 22% greater reduction in WBV exposure from just the seat pad alone, compared to the stock foam seat currently in use (see Figure 3).

Figure 3. Vibration Transmitted from Bus Floor to Driver's Seat



Note: The stock foam cushion attenuates only 11% of the vibration exposure, while the ballistic air-filled seat pad (with the foam seat cushion removed) attenuates 33% of the vibration exposure.

The current study evaluates professional semi-truck drivers' WBV exposure on different road conditions, including freeways, highways, city streets, and off-road.

Specific Aims

1. To measure, characterize, and analyze WBV exposures over a standardized route; WBV exposures will be collected in series, on the truck floor, on the stock air-suspension seat, and on the ballistic air-filled seat pad placed on top of the air-suspension seat, used by nine semi-truck drivers. WBV exposures will be collected in accordance with ISO 2631-1 (1997) and ISO 2631-5 (2004), which use time-weighted average A(8) and continuous impulse vibration exposure VDV(8), respectively.

2. To compare the median WBV exposures with box and whisker plots and Wilcoxon signed rank tests to determine if there are significant differences amongst the three exposures to determine the effectiveness of the ballistic air-filled seat pad.

The current study measured truck drivers' exposure to WBV and determined whether there were differences between the WBV exposures measured at the seat top of an industry standard air-suspension seat and on the ballistic air-filled seat pad set on top of the air-suspension seat as an additional layer to further attenuate the driver's exposures to WBV. It was hypothesized that the seat pad would significantly reduce the truck drivers' exposures to WBV relative to the WBV measures at the top of the stock air-suspension seat. Ultimately, if the ballistic seat pad was found to reduce WBV exposure, it could potentially decrease the incidence, prevalence, and severity of semi-truck drivers' low back pain. Drivers could potentially drive for longer periods of time with less discomfort. Cost-savings from a cheaper alternative to active air-suspension seats—let alone from decreases in medical and surgical treatment costs, workers' compensation, lost work days, and lost work productivity—could be substantial.

Methods

The study compared repeated measures of WBV exposure in nine professional semi-truck drivers. The study was approved by the University of Washington's Human Subjects Committee, and informed consent was obtained. The range of ages of the drivers was 42 to 64, with a mean of 54. Their mean weight was 213 lbs., with a standard deviation of 58 lbs. Associated demographic data are provided in Table 4.

Table 4. Demographics of Study Participants

Subject	Age	Height (cm)	Weight (lb)	BMI
S02	53	170	190	29.8
S04	44	178	220	31.6
S05	55	163	160	27.5
S06	56	178	160	23.0
S07	64	165	175	29.1
S10	53	193	350	42.6
S11	56	180	220	30.7
S12	42	183	225	30.5
S15	63	180	220	30.7
Median (IQR)	55 (11)	178 (14)	220 (55)	30.5 (2.85)

In a 72,000 kg nine-axle truck (Model 4500-2014; Western Star; City, State) (see Figure 4), WBV measurements were collected on the floor, on the drivers' existing air-suspension seat, and on the seat pad, which sat on top of their seat. The same stock air-suspension seat was used by all nine drivers.

Figure 4. Western Star Model 4500 (2014), the Semi-Truck Model Used in the Study

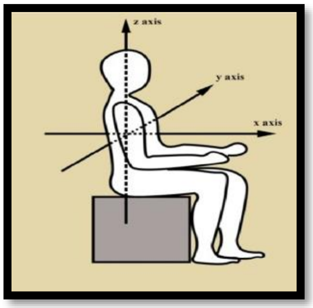
A tri-axial seat pad accelerometer (PCB Piezotronics; Model 356B40; Depew, NY) was used to collect the WBV exposures from the seat and seat pad and a third accelerometer was magnetically mounted to the floor below the truck driver's seat in order to measure the vibration levels on the truck floor (see figure 5).

Figure 5. A Tri-Axial Seat Pad Accelerometer, Similar to the Ones Used in the Study

Rion-20 and Rion-40 series vibration monitors collected tri-axial (x-direction, or fore-aft; y-direction, or side to side; and z-direction, or up and down) WBV simultaneously (see Figure 6 and Appendix B).

By convention, according to the International Standards Organization (ISO) 2631-1 Whole Body Vibration standard (37), the highest value of the three directions was used to characterize the exposure, as was the vector sum (Σxyz) to characterize total exposure. The WBV exposure data was collected at 1280 Hz per channel and all data analyses were performed in accordance with International Standards Organization 2631-1 (1997) and ISO-2631-5 (2004) (see Appendix B).

Figure 6. A Basicentric Seated Model Depicting the Three Axes

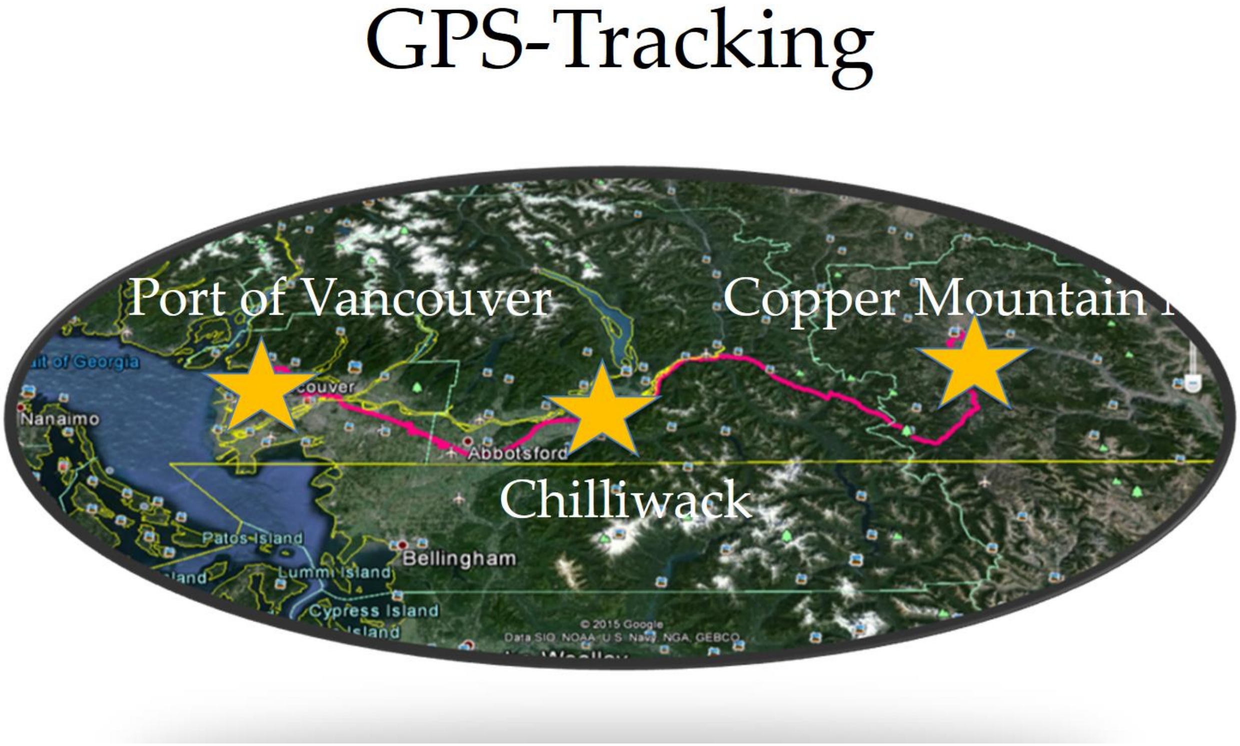


Note: Axes include the x-direction, or fore-aft; y-direction, or side to side; and z-direction, or up and down.

In addition, a GPS unit recorded the truck's progress along the route at one-second intervals. Subsequently, the WBV exposure data and GPS data were combined which allowed the WBV exposures data to be analyzed by the various road segments traversed by the trucks.

The subjects drove the same truck on the same standardized route which was used to pick up aggregate materials from mines and deliver the materials to a port in the city of Vancouver, British Columbia. The round-trip originated in Chilliwack, British Columbia, proceeded east to the mines where the trucks were loaded with aggregate, and then west to the Port of Vancouver where the aggregate material was unloaded, and then returned east to the terminal in Chilliwack (see Figure 7). The route included two lane freeways, single lane highways, city streets in the port and an unpaved road in and out of the mine. The trucks had no loads when driving to the mine and when returning from the port to the truck terminal in Chilliwack, and were loaded when driving from the mine to the port. It took the truck drivers roughly eleven hours to circumnavigate the whole 800-km route.

Figure 7. The Standardized Route Used in the Study



Note: The round-trip originated in Chilliwack, British Columbia, and proceeded east to the Copper Mountain mines where the semi-trucks were loaded with aggregate. The trucks then drove west to the Port of Vancouver where the aggregate material was unloaded. The trucks then returned to the terminal in Chilliwack.

The three accelerometers were calibrated prior to the data collection with an exciter (Bruel & Kjaer; Type 4294) with 10 m/s^2 r.m.s.; oscillation frequency was 159.2 Hz. WBV exposures collected in accordance with ISO 2631-1 and ISO 2631-5 included:

(i) Weighted root mean square (r.m.s.) average vibration (A_w) normalized to an 8-hour work day, A(8), in m/s^2

(ii) Vibration Dose Value normalized to an 8-hour work day, VDV(8), in $m/s^{1.75}$

LabVIEW (National Instruments; v2014; Austin, TX) software was used to verify the calibration.

WBV values were measured for each route segment. Data was collected using a four-channel recorder (Rion Co., LTD; Model DA-20 and DA-40; Tokyo, Japan) (see Appendix B). Raw tri-axial accelerations were collected at 1280 Hz per channel by seat pad ICP accelerometers (PCB Piezotronics; Model 356B40; Depew, NY) mounted on the driver's seat and on top of the ballistic air-filled seat pad. A third accelerometer was installed magnetically on the floor beneath the driver's seat. Data was stored on a memory card (San Disk; Extreme III; Milpitas, CA). GPS data was collected at one-second intervals (Global Sat; Model DG-100; Chino, CA), allowing for speed and location information to be matched with vibration data.

LabVIEW post-processing software was used to synchronize the data collection. A program with graphical interface calculated ISO 2631-1 and ISO 2631-5 values, with output into Microsoft Excel. Error checks used a mean of 1 m/s^2, standard deviation of 3 m/s^2, and a peak of 40 m/s^2.

JMP (v12; SAS Institute; Cacy, SC) was used to conduct the statistical analysis. To determine if there were differences in WBV exposure between the floor and the seat, and the seat and the ballistic air-filled seat pad, Wilcoxon signed rank tests were performed. These tests produced p-values. The significance level used was a p-value of not higher than 0.05; p-values above 0.05 indicate no difference in WBV exposure was observed. Medians and interquartile ranges of measured WBV exposure values were compared, as well, in box and whisker plots.

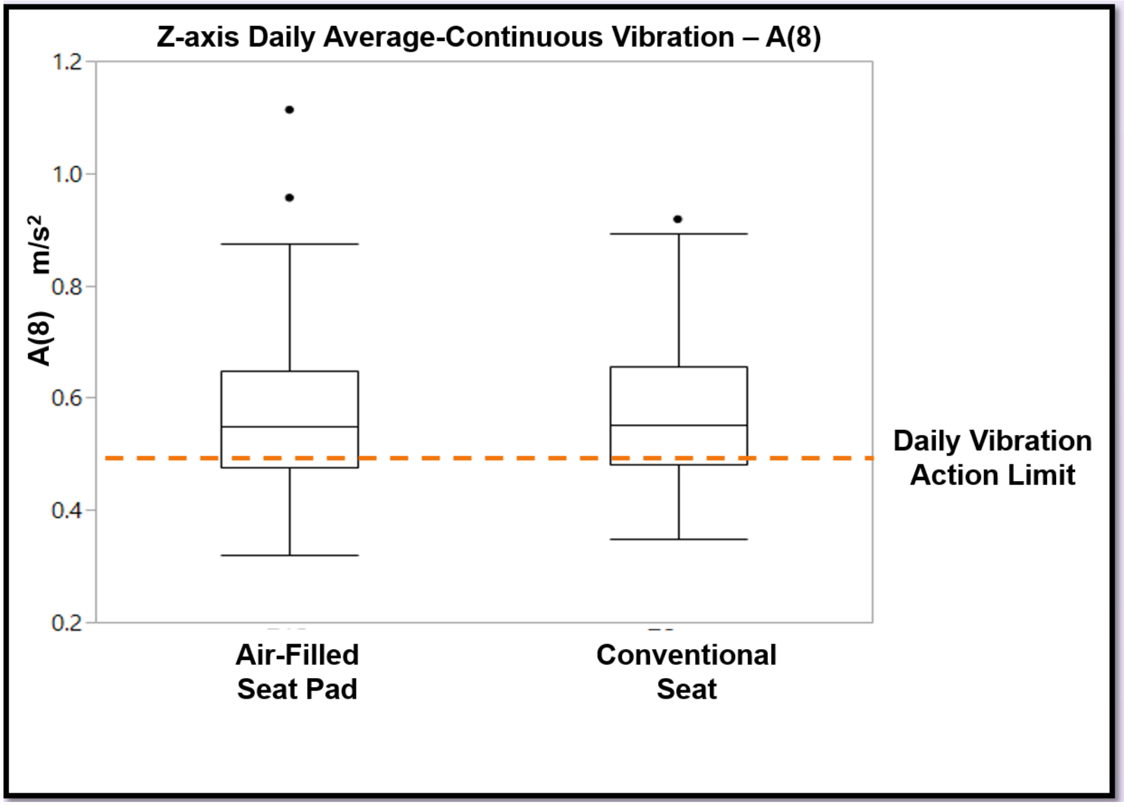
Wilcoxon signed rank tests are non-parametric. With the notable exception of an assumption of symmetry, few assumptions are made, and no assumption is made with regard to normality, in particular. It is a robust method, not unduly affected by outliers (62). It is intended to compare at least eight matched samples. This corroborates an analysis that was performed to ensure adequate power; results are provided in Appendix A.

As a paired-difference test between measures, Wilcoxon signed rank tests are well-suited to compare the WBV exposures measured at the top of the nine drivers' existing air-suspension seat relative to the WBV exposures measured at the ballistic air-filled seat pad which sat on top of the driver's seat. In addition, to determine the effectiveness of the seat itself in attenuating vibration exposure, WBV exposure measured at the top of the seat were compared to the vibration levels collected from the truck's floor.

Results

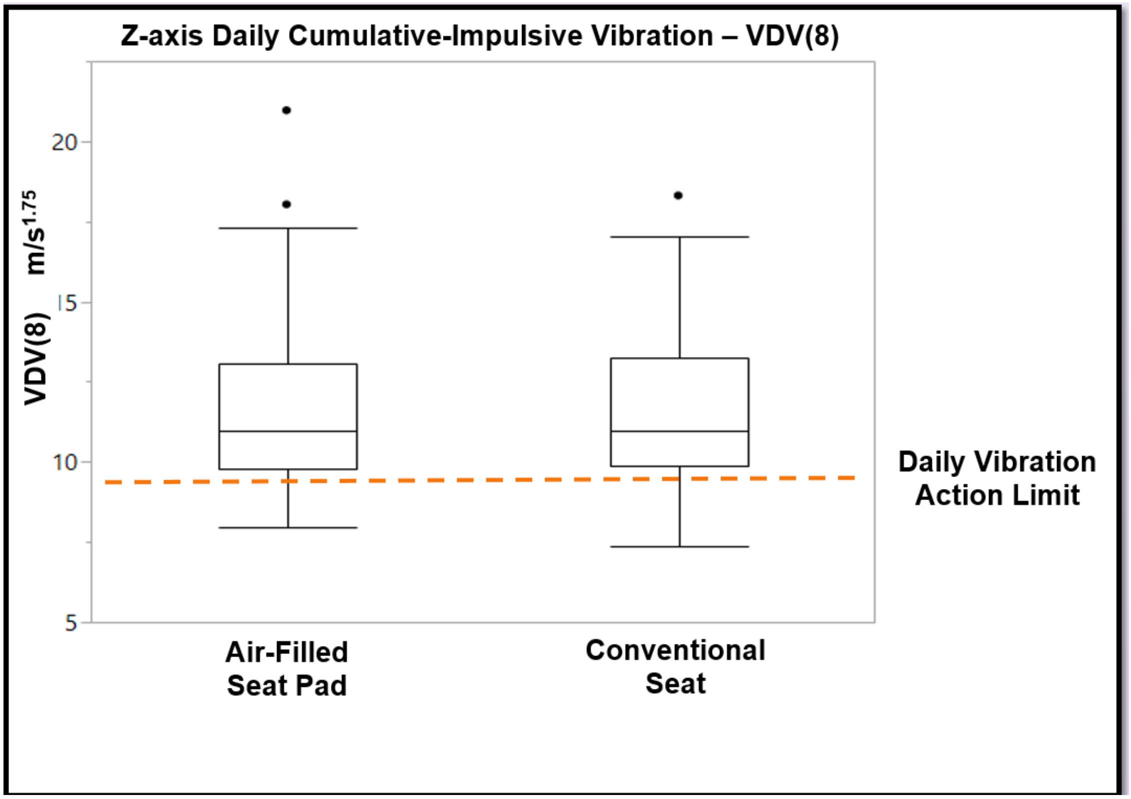
Over the full route, truck drivers' vibration exposures were above European Union daily vibration action values and the air-filled ballistic seat pad did not significantly reduce those exposures. Overall A(8) and VDV(8) exposures are summarized in Figure 8 and Figure 9, respectively. These two figures are the first of many indications from this study that neither the stock air-suspension seat nor the ballistic air-filled seat pad were effective in reducing drivers' WBV exposure.

Figure 8. Overall Comparison of the WBV Exposures from a Ballistic Air-Filled Seat Pad and a Conventional Air-Suspension Seat: Z-Axis Daily Average Continuous Vibration—A(8)



Note: Box and whisker plots compare the z-axis average daily-weighted vibration between the seat pad and the top of air-suspension seat. The dashed lines show the daily vibration action value (0.5 m/s^2). European Union daily vibration action values were exceeded.

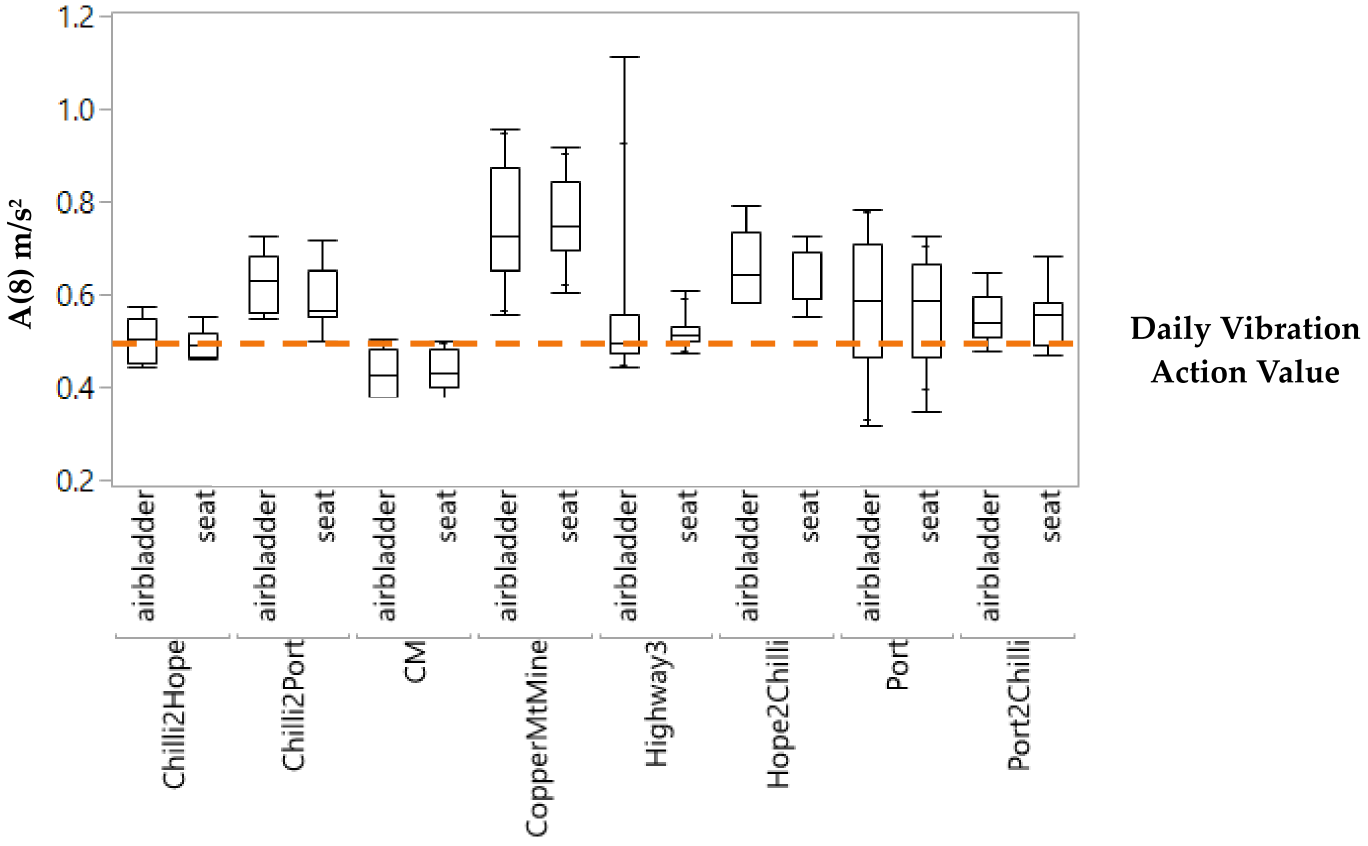
Figure 9. Overall Comparison of the WBV Exposures from a Ballistic Air-Filled Seat Pad and a Conventional Air-Suspension Seat: Z-Axis Daily Average Continuous Impulsive Vibration—VDV(8)



Note: Box and whisker plots below compare the z-axis average daily-weighted vibration between the seat pad and the top of air-suspension seat. The dashed lines show the daily vibration action value (9 m/s$^{1.75}$). European Union daily vibration action values were exceeded.

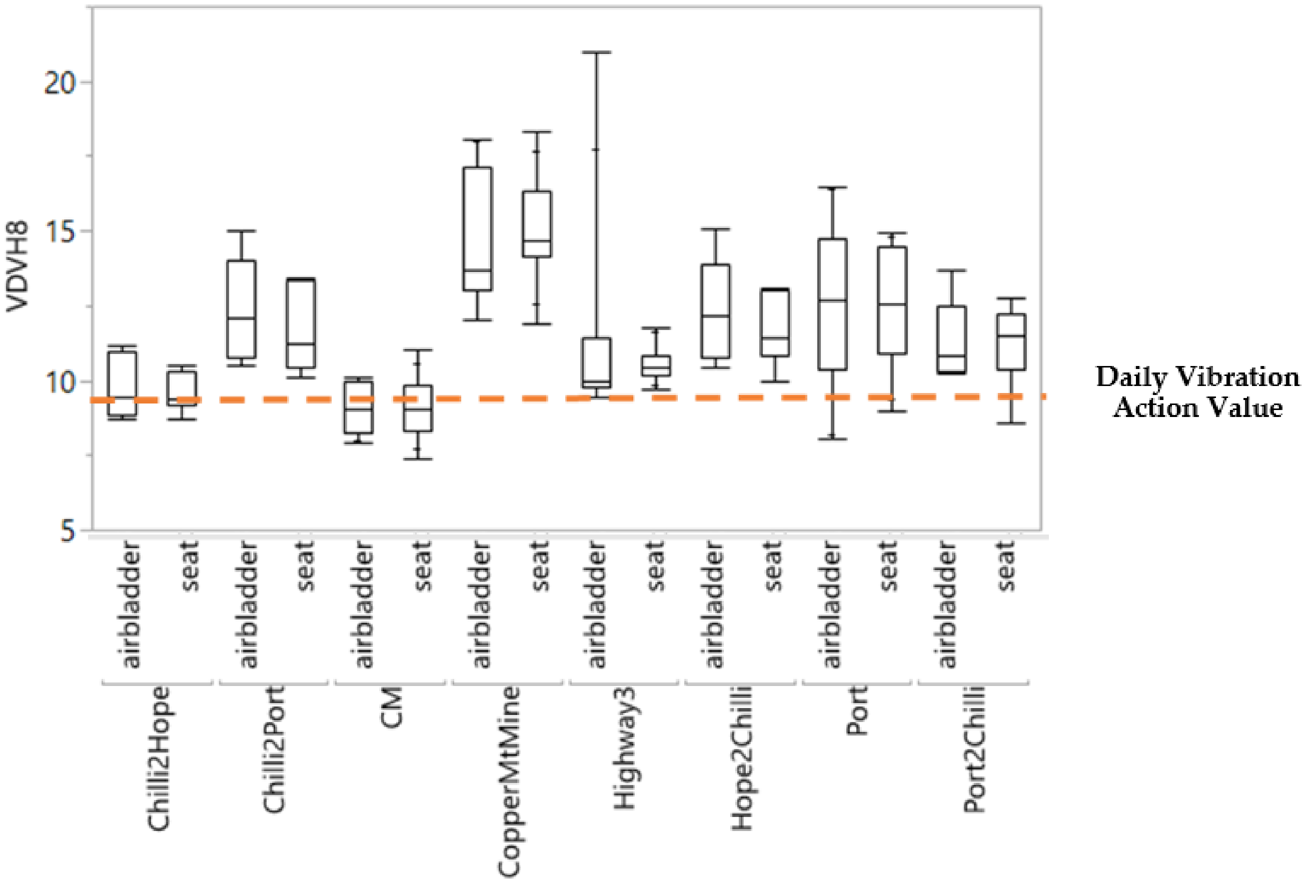
Additional data analyses were performed to determine whether there were differences between the seat and seat pad WBV exposure across different segments of the route. Associated graphs of A(8) and VDV(8) are presented in Figures 10 and 11, below.

Figure 10. Comparison of the WBV Exposures from a Ballistic Air-Filled Seat Pad and a Conventional Air-Suspension Seat by Route Segment: Z-Axis Daily Average Continuous Vibration—A(8)



Note: Box and whisker plots below compare the z-axis average daily-weighted vibration between the seat pad and the top of air-suspension seat. The dashed lines show the daily vibration action value (0.5 m/s²). With the exception of the Copper Mountain (CM), British Columbia, route segment, European Union daily vibration action values were exceeded. Other route segments in British Columbia listed are: Chilliwack to Hope; Chilliwack to the Port of Vancouver; Copper Mountain Mine; Highway 3; Hope to Chilliwack; the Port of Vancouver; and the Port of Vancouver to Chilliwack.

Figure 11. Comparison of the WBV Exposures from a Ballistic Air-Filled Seat Pad and a Conventional Air-Suspension Seat by Route Segment: Z-Axis Daily Average Continuous Impulsive Vibration—VDV(8)



Note: Box and whisker plots compare the z-axis average daily-weighted vibration between the seat pad and the top of air-suspension seat. The dashed lines show the daily vibration action value (9 m/s$^{1.75}$). The European Union daily vibration action value was exceeded here, as well. Route segments in British Columbia listed are: Chilliwack to Hope; Chilliwack to the Port of Vancouver; Copper Mountain (CM); Copper Mountain Mine; Highway 3; Hope to Chilliwack; the Port of Vancouver; and the Port of Vancouver to Chilliwack.

With respect to different route segments, as depicted in Figure 10 and Figure 11, the truck drivers' vibration exposures were above European Union daily vibration action values. The only exception was the A(8) exposure on the Copper Mountain route segment (see Figure 10 above). The seat pad did not significantly reduce WBV exposures. Note, too, that the highest WBV exposures were associated with the off-road segment leading into and out of the Copper Mountain Mine.

Wilcoxon signed rank tests confirmed the findings (see Tables 5-8).

Table 5. A(8) Floor-Seat Matched Pairs Difference: Median (IQR) and p-Values

	Floor	Seat	P-value
Freeway (Chilliwack-Port of Vancouver)	0.65 (0.60 – 0.72)	0.57 (0.53 – 0.65)	**0.11**
Highway (Copper Mountain)	0.44 (0.38 – 0.50)	0.43 (0.38 – 0.48)	**0.30**
Off-Road (Copper Mountain Mine)	0.84 (0.75 – 0.96)	0.76 (0.66 – 0.88)	**0.37**
City Streets (Port of Vancouver)	0.57 (0.52 – 0.67)	0.56 (0.46 – 0.65)	**0.64**

Table 6. A(8) Seat-Seat Pad Matched Pairs Difference: Median (IQR) and p-Values

	Seat	Seat Pad	P-value
Freeway (Chilliwack-Port of Vancouver)	0.57 (0.53 – 0.65)	0.62 (0.55 – 0.64)	**0.16**
Highway (Copper Mountain)	0.43 (0.38 – 0.48)	0.48 (0.37 – 0.50)	**0.44**
Off-Road (Copper Mountain Mine)	0.76 (0.66 – 0.88)	0.74 (0.64 – 0.85)	**0.44**
City Streets (Port of Vancouver)	0.56 (0.46 – 0.65)	0.60 (0.45 – 0.70)	**0.22**

In Table 5, regardless of road condition, there were no significant A(8) Floor-Seat p-values. In Table 6, regardless of road condition, there were no significant A(8) Seat-Seat Pad p-values. In Table 7, with respect to road condition, the only significant VDV(8) Floor-Seat p-value was from the freeway from Chilliwack to Port of Vancouver.

Table 7. VDV(8) Floor-Seat Matched Pairs Difference: Median (IQR) and p-Values

	Floor	Seat	P-value
Freeway (Chilliwack-Port of Vancouver)	13.4 (12.4 – 13.9)	11.1 (10.2 – 13.3)	**0.02**
Highway (Copper Mountain)	9.1 (8.1 – 11.8)	8.8 (8.1 – 9.8)	**0.16**
Off-Road (Copper Mountain Mine)	17.4 (14.9 – 19.2)	14.4 (13.5 – 16.1)	**0.08**
City Streets (Port of Vancouver)	13.5 (12.1 – 14.7)	12.6 (9.9 – 14.2)	**0.55**

Table 8. VDV(8) Seat-Seat Pad Matched Pairs Difference: Median (IQR) and p-Values

	Seat	Seat Pad	P-value
Freeway (Chilliwack-Port of Vancouver)	11.1 (10.2 – 13.3)	12.1 (10.5 – 12.9)	**0.16**
Highway (Copper Mountain)	8.8 (8.1 – 9.8)	9.8 (8.1 – 10.1)	**0.62**
Off-Road (Copper Mountain Mine)	14.4 (13.5 – 16.1)	13.9 (12.6 – 16.3)	**0.44**
City Streets (Port of Vancouver)	12.6 (9.9 – 14.2)	12.8 (9.2 – 14.3)	**0.22**

In Table 8, regardless of road condition, there were no significant VDV(8) Seat-Seat Pad p-Values.

With virtually every road condition and route segment, there were no significant p-values, i.e., there was no difference in WBV exposure measured at the existing seat and at the ballistic seat pad. In other words, the seat pad did not significantly attenuate WBV exposure. Interestingly, there was only one significant difference in WBV exposures measured at the floor and the existing seat, (see Table 7). In other words, the seat itself did not effectively attenuate WBV from the floor.

Figure 12. Comparison of the WBV Exposures by Off-Road Segment (Copper Mountain Mine) and On-Road Segment (Port): Z-Axis Daily Average Continuous Vibration—A(8)

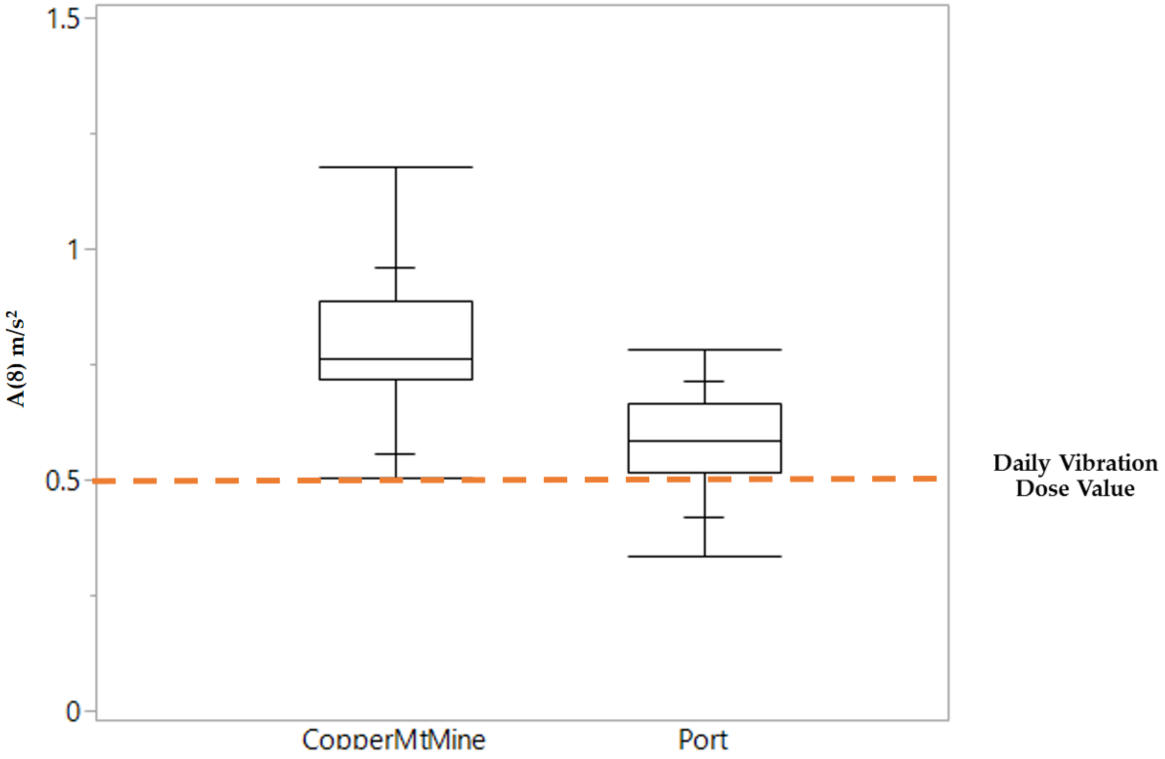


Figure 13. Comparison of the WBV Exposures by Off-Road Segment (Copper Mountain Mine) and On-Road Segment (Port): Z-Axis Daily Average Continuous Impulsive Vibration—VDV(8)

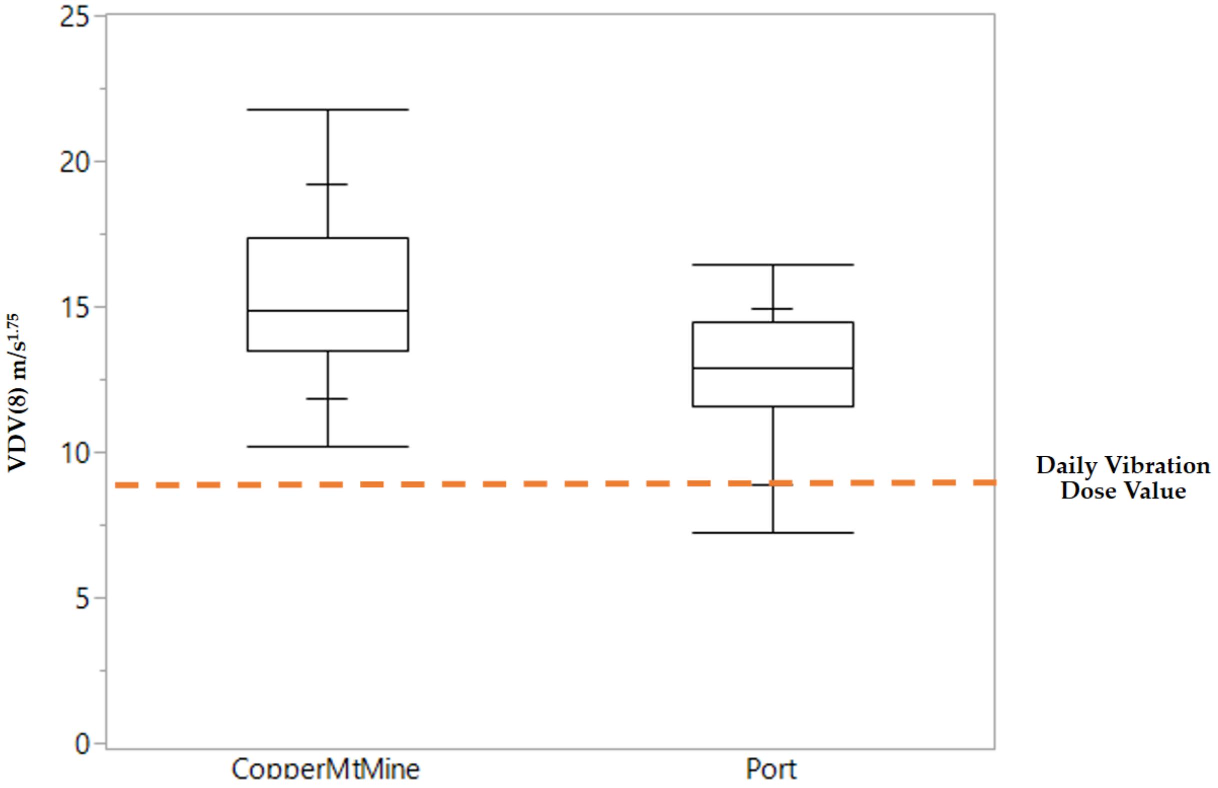


Table 9. A(8) and VDV(8) On-Road and Off-Road Matched Pairs Difference: Median (IQR) and p-Values

	On-Road	Off-Road	P-value
A(8) m/s^2	0.58 (0.54-0.62)	0.79 (0.75-0.83)	**<0.0001**
VDV(8) $m/s^{1.75}$	12.58 (11.88-13.28)	15.39 (14.69-16.09)	**<0.0004**

Note: This comparison of road conditions only, with the truck loaded with aggregate and driven at similar speeds, indicates a significant difference in WBV exposure, as one might expect.

With respect to on-road and off-road conditions, the truck drivers' vibration exposures were above European Union daily vibration action values and the seat pad did not significantly reduce WBV exposures (see Table 9 and Figure 12 and Figure 13).

Discussion

The same truck was used for each of the nine professional drivers. Each driver drove it at comparable speeds on each individual route segment, including freeways, highways, city streets, and off-roads. Each driver's WBV exposure was measured in series—at the floor, at the stock air-suspension seat, and at the ballistic air-filled seat pad. This is similar to a previous University of Washington study that involved just 13 bus drivers.

On a route of approximately 800 km and a duration of eleven hours, tens of thousands of matched observations were collected, at one-second intervals.

A power analysis of this study was performed, which suggested that as few as eight drivers may be needed. This observation is corroborated by other similar studies (60) with even fewer study participants. Wilcoxon signed rank tests are well-suited to matched pairs analysis with a sample size of at least eight, as well. It is a non-parametric, robust test, that is not unduly affected by outliers. Though the risk of making a Type II error exists, it is no more likely than any other small, negative study making the same assumptions with regard to significance level.

The fact that the ballistic air-filled seat pad—as well as the seat itself—did not significantly reduce WBV exposure was surprising, based upon previous studies involving use of the seat pad in buses. The question of whether the seat pad may significantly reduce the incidence, prevalence, or severity of low back pain in semi-truck drivers remains, but it appears unlikely that the seat pad can do so based upon the WBV exposures observed in this study. WBV exposures exceeding the daily vibration action value put truck drivers at moderate to severe risk of developing adverse health outcomes, and the seat pad did little to diminish them.

Due to the surprising ineffectiveness of the stock air-suspension seat, it deserves closer inspection. Questions arise with regard to whether there is something about that particular seat that made it ineffective with regard to attenuating drivers' WBV exposure, or whether it is part of a bigger systemic problem associated with all seats of the same type.

In light of the seat and the seat pad's ineffectiveness, there is an opportunity here for administrative controls to make a difference with regard to reducing the truck drivers' WBV exposure. One example would be to change drivers in Chilliwack, reducing the time each driver spends in the truck by approximately half.

The answer to why the seat pad was not effective may lie in a future analysis of power spectral densities. Power spectral densities are measures of vibration intensity across a frequency spectrum. With regard to drivers' exposure to WBV, buses and trucks are not created equal. The first indication is the location of the operator's cab relative to the front axle (see Figure 14 and Figure 15). There is another key difference that is inherently related to cab position. Buses produce more high frequency energy to which the driver is exposed, where the air-filled seat pad was effective. Trucks produce less high frequency energy to which the driver is exposed, which may diminish the air-filled seat pad’s relative effectiveness (note the relative intensities of the power spikes at 10 Hz in Figure 16 and Figure 17).

Figure 14. A Cab-Forward Bus

Note: The bus driver’s cab is located in front of the front axle, increasing high frequency energy.

Figure 15. The Truck Model Used in the Study

Note: The truck’s cab is located behind the front axle, reducing high frequency energy.

Figure 16.

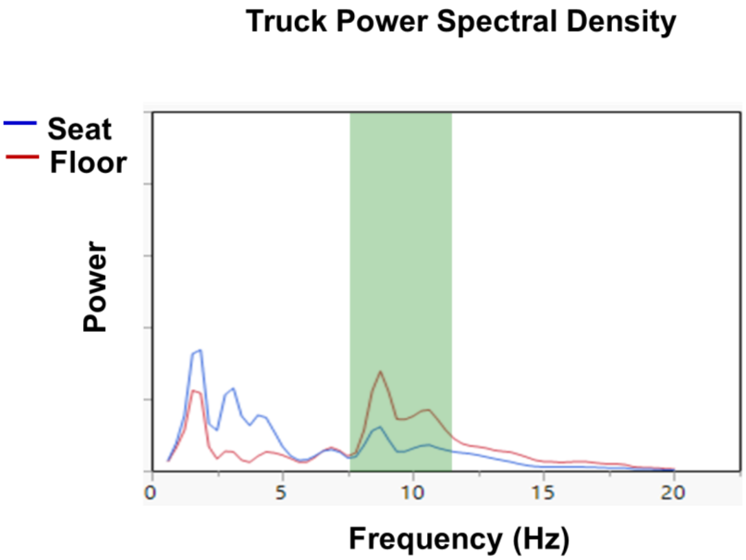
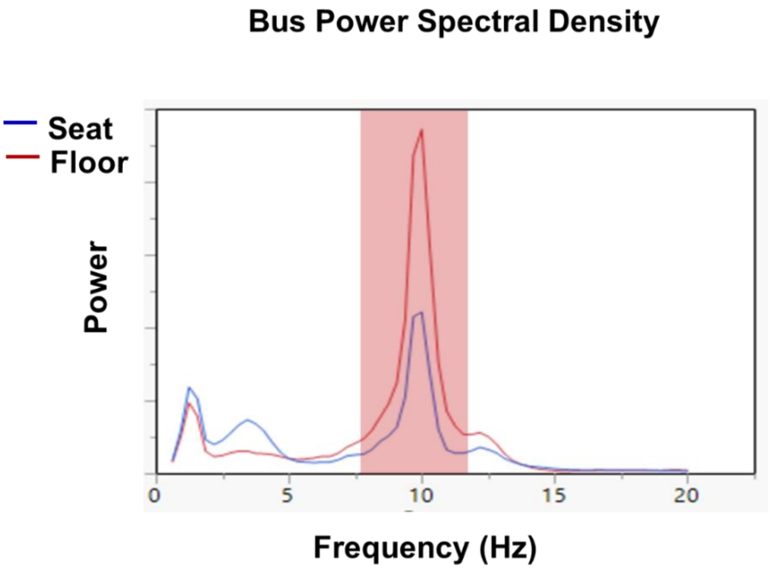


Figure 17.



Note: Vibration energy is extremely high at 10 Hz in this bus power spectral density graph, in contrast to the previous graph of truck power spectral density.

Based upon these observations, the ballistic, air-filled seat pad may be better suited to buses, and perhaps to smaller cab-forward construction vehicles. It is an intriguing possibility that will likely be investigated in follow-up studies.

Limitations: A small number of drivers volunteered to participate in the study, due to time and financial constraints. Demographic data presented in Table 4 was self-reported, permitting reporting and recall bias, likely leading to some inaccuracy. Truck availability was an issue, as well. The truck involved in the study was a maintenance back-up. It was subject to recall to replace other trucks which would break down frequently, due to the strenuous nature of hauling heavy loads of copper ore long distances up and down steep mountain passes. The impact of these limitations was minimized by reliance upon objective measures of WBV exposure and appropriate statistical analyses, which were corroborated by a power analysis.

Conclusions

With regard to WBV exposure, there was only one significant difference in effect between the floor and the truck's air-suspension seat, and no significant difference in effect between the truck's air-suspension seat and the air-filled ballistic seat pad. Reduction of WBV exposure in a cost-effective manner remains an elusive goal. Air-suspension seats are expensive, and based on this study, not always effective; the seat pad is a cheaper alternative, but it was not effective, either.

This intervention's long-term goal is to reduce commercial motor vehicle drivers' disability and pain. Surprisingly, this study did not demonstrate a significant reduction of WBV exposure in semi-truck drivers, as had been demonstrated previously in a study of bus drivers. An explanation for this disparity in exposures between drivers of semi-trucks and buses, may lie in a future analysis of associated power spectral densities (61).

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and have found that it is complete and satisfactory in all respects, and that any and all revisions required by the final examining committee have been made.

Committee Members:

____ Peter W. Johnson

____ Sverre Vedal

____ Gregory J. Martin

Date:______________________________

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Appendix A.

Whole Body Vibration Exposure Sample Size Calculations

Assumptions:

Study design: Two independent study groups

Primary endpoint: Continuous (medians)

Type I/II error rate: Alpha 0.05, Power 80%

Group 1 (Control): 100Hz+/-10Hz

Sample Size formula: n1 = (σ1^2 + σ2^2/k)(zsub1- α/2 + zsub1- β)^2/ Δ^2

Sample Size Calculation:

Group 2 (Intervention arm): 20% anticipated attenuation

n1 = (10^2 + 10^2/1)(1.96 + 0.84)^2/20^2

Total Sample Size = 8

Where:

$\Delta = |\mu2\text{-}\mu1|$ = absolute difference between two means

$\sigma1$, $\sigma2$ = variance of mean #1 and #2

n1 = sample size for group #1

α = probability of type I error (usually 0.05)

β = probability of type II error (usually 0.2)

z = critical Z value for a given α or β

k = ratio of sample size for group #1 to group #2 (54)

Appendix B.

Subject ID: _________ Study site: ____ Investigator: ______ Date: ____ /____ /____

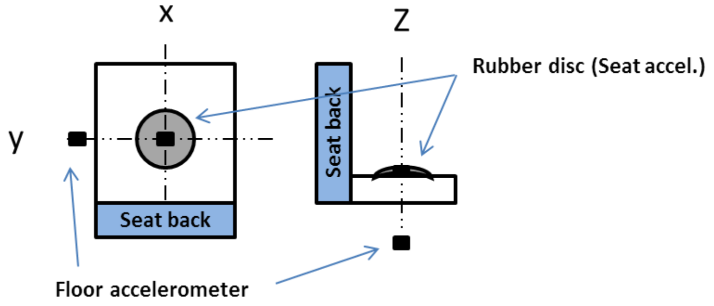
Subject First Name: ______________________________ Truck#________ M#_______ Time Point: ___

Key Location: _______________________ Shift Start Time: ____________ Shift End Time: ____________

APPARATUS

Vehicle	**Make:** ______________ **Model:** ______________ **Year:** ______________ **Mileage:** ____________
Seat	**Type:**

Data Collection

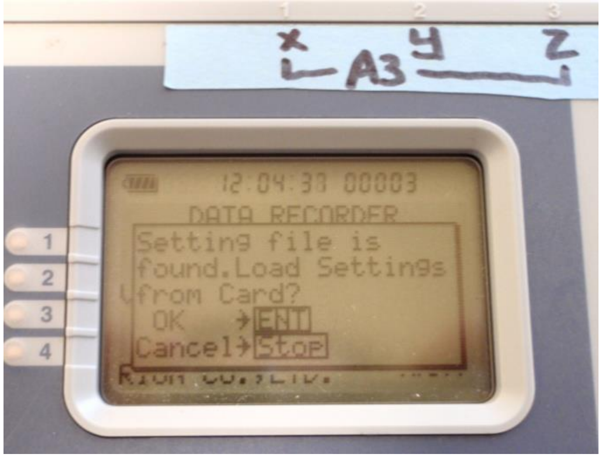
	Installation	
		
	Turn on the Rion data logger and check the settings	
	Settings: Range: 3.00 x 10^2 m/s^2 (3V) Input: CCLD, HPF Off, LPF Off, Sens PICK Frequency Range: 500Hz Sampling Freq: x2.56Hz Check Date/Time	
	Seat accelerometer (X, Y, Z) => Ch. 1, 2, 3	
	8-channel logger	**Floor** accelerometer (X, Y, Z) => Ch. 4, 5, 6
	4-channel logger	**Floor** accelerometer (Z) => Ch. 4
	Press record - time (__ __ : __ __)	
	Oscillate all accelerometers (3x X direction – away 1st, 6x Y direction right 1st, 9x Z direction up 1st)	
	Post measurement	
	Turn off the Rion data logger and GPS (__ __ : __ __)	
	Away from site	
	Download GPS, save as .csv .gpx, .nmea .kml with name; save map STUDY_TIMEPOINT_M000_SITE_T00000_SEAT_GPS00_YYYYMMDD	
	Move Rion file and save as STUDY_TIMEPOINT_M000_SITE_T00000_SEAT_RION0_YYYYMMDD	
	Check GPS and Rion files for quality, process to power file, and backup on iDrive	
	Recharge Rion internal batteries (C or AA)	
	Recharge GPS	
	Recharge external batteries	

WBV HARDWARE

Logger ID	Model	Channel	CF card #	Battery	Seat Accel. #	Seat Cable #	Floor Accel. #	Floor Cable #	GPS Unit #
#1	RION DA-20	4	1	1	A7	7	S2	1002	20
#2	RION DA-20	4	2	5	A8	16	S3	1003	21
#3	RION DA-20	4	3	6	A1	10	S4	1001	22
#4	RION DA-40	8	4	7	A6	6	A4	3	23
#5	RION DA-40	8	5	11	A2	20	A5	10	24 25
#6	RION DA-40	8	6	12	A9	1004	A3	22	26 27
#7	RION DA-40	8	7 8	14 15	A10	17	S1	1000	28 29

0.1 Start RION by pressing POWER. ***Photos on the left are for the DA-20, photos on right for DA-40.***

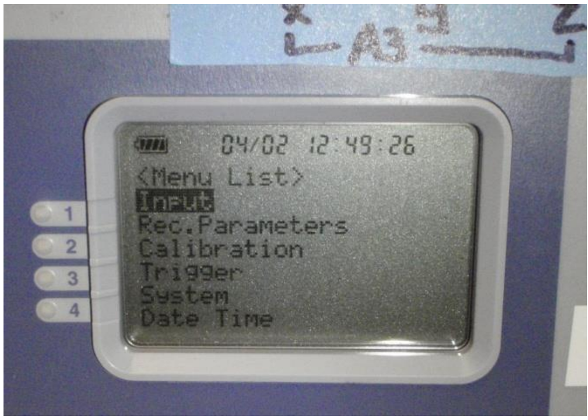
0.2 This may appear, to ask if you want to save setting from card:

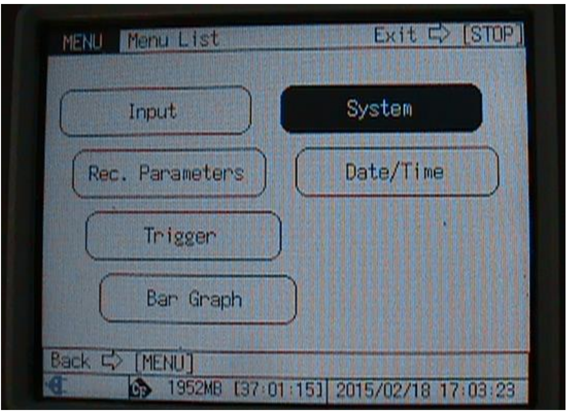


12:04:33 00003
DATA RECORDER
Setting file is found.Load Settings from Card?
OK → ENT
Cancel→ Stop
RION CO.,LTD.

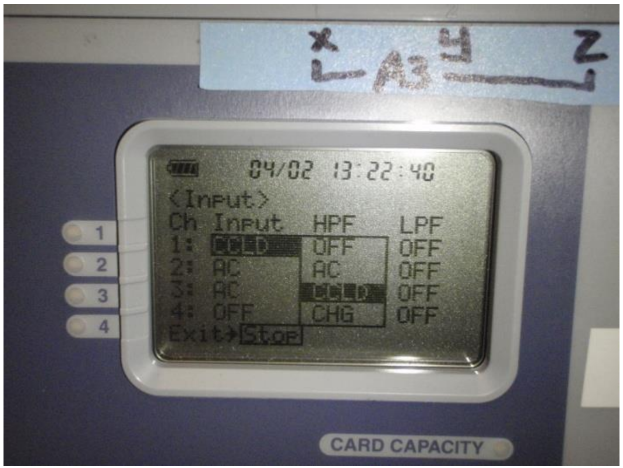
0.3 Chose Cancel

1.0 Press MENU, and choose Input.

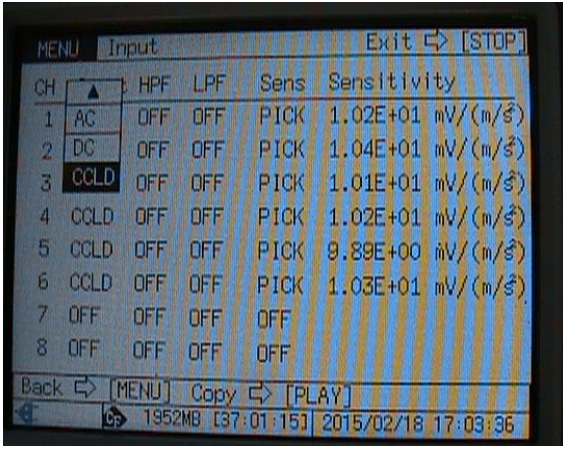




1.1 Make sure (or change so) Input for channel 1, 2 and 3 is CCLD, and that HPF and LPF is OFF.

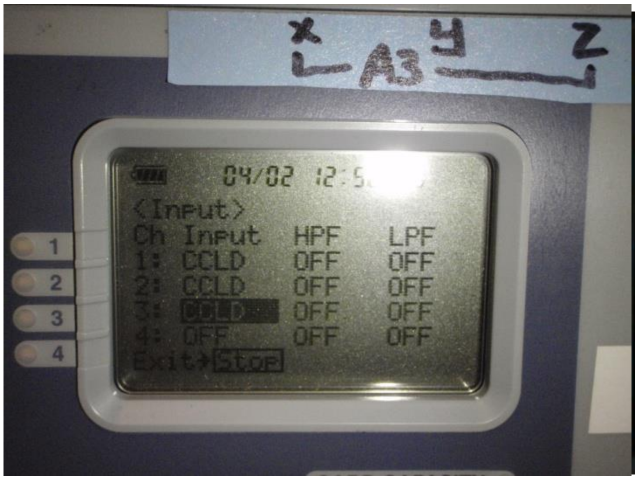


```
04/02 13:22:40
<Input>
Ch Input  HPF  LPF
1: CCLD   OFF  OFF
2: AC     AC   OFF
3: AC     CCLD OFF
4: OFF    CHG  OFF
Exit→Stop
```



```
MENU  Input                          Exit ⇨ [STOP]
CH   ▲    HPF  LPF  Sens  Sensitivity
1   AC    OFF  OFF  PICK  1.02E+01 mV/(m/s²)
2   DC    OFF  OFF  PICK  1.04E+01 mV/(m/s²)
3   CCLD  OFF  OFF  PICK  1.01E+01 mV/(m/s²)
4   CCLD  OFF  OFF  PICK  1.02E+01 mV/(m/s²)
5   CCLD  OFF  OFF  PICK  9.89E+00 mV/(m/s²)
6   CCLD  OFF  OFF  PICK  1.03E+01 mV/(m/s²)
7   OFF   OFF  OFF  OFF
8   OFF   OFF  OFF  OFF
Back ⇨ [MENU]  Copy ⇨ [PLAY]
     1952MB [37:01:15] 2015/02/18 17:03:36
```

Should look like this:



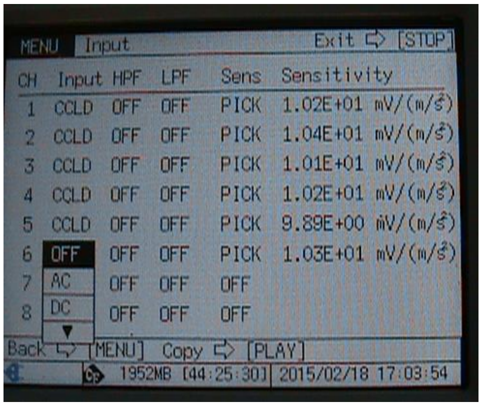
```
04/02 12:5
<Input>
Ch Input  HPF  LPF
1: CCLD   OFF  OFF
2: CCLD   OFF  OFF
3: CCLD   OFF  OFF
4: OFF    OFF  OFF
Exit→Stop
```

```
MENU  Input                          Exit ⇨ [STOP]
CH  Input HPF  LPF  Sens  Sens  +  ty
1   CCLD  OFF  OFF  PICK  1.02 +01 mV/(m/s²)
2   CCLD  OFF  OFF  PICK  1.04  -  mV/(m/s²)
3   CCLD  OFF  OFF  PICK  1.01E+01 mV/(m/s²)
4   CCLD  OFF  OFF  PICK  1.02E+01 mV/(m/s²)
5   CCLD  OFF  OFF  PICK  9.89E+00 mV/(m/s²)
6   CCLD  OFF  OFF  PICK  1.03E+01 mV/(m/s²)
7   OFF   OFF  OFF  OFF
8   OFF   OFF  OFF  OFF
Back ⇨ [MENU]  Copy ⇨ [PLAY]
     1952MB [37:01:15] 2015/02/18 17:04:24
```

1.2 For the DA-40, ensure Sens is set to PICK and sensitivity is appropriate for attached accelerometers. Instructions on adjusting sensitivity are in step 2.4.

1.3 For the DA-40: Turn off any channels that will not be used such as channels 7 and 8:

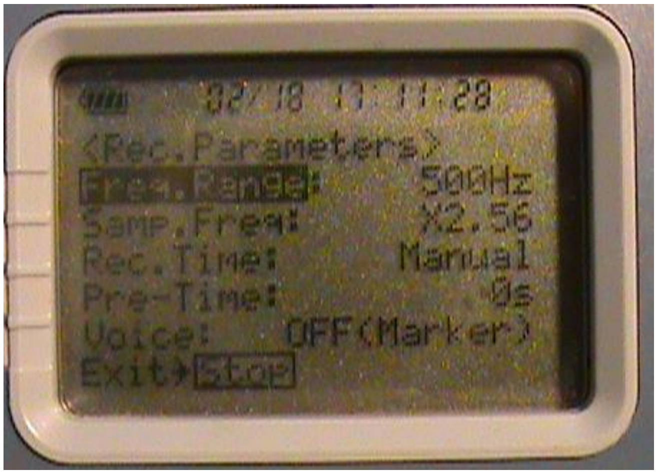
Menu -> Input Change Input to OFF for any unused channels.



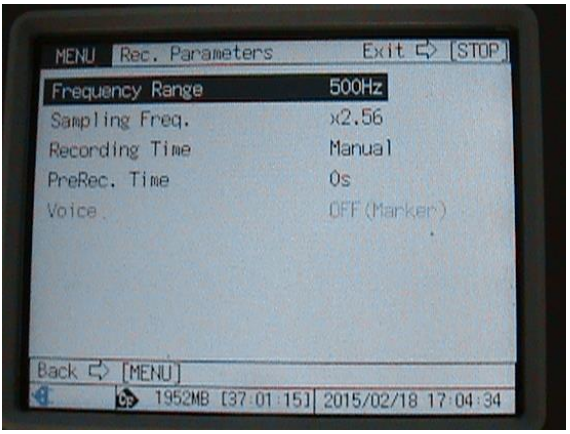
CH	Input	HPF	LPF	Sens	Sensitivity
1	CCLD	OFF	OFF	PICK	1.02E+01 mV/(m/s²)
2	CCLD	OFF	OFF	PICK	1.04E+01 mV/(m/s²)
3	CCLD	OFF	OFF	PICK	1.01E+01 mV/(m/s²)
4	CCLD	OFF	OFF	PICK	1.02E+01 mV/(m/s²)
5	CCLD	OFF	OFF	PICK	9.89E+00 mV/(m/s²)
6	OFF	OFF	OFF	PICK	1.03E+01 mV/(m/s²)
7		OFF	OFF	OFF	
8		OFF	OFF	OFF	

1952MB [44:25:30] 2015/02/18 17:03:54

2.0 Go to MENU, choose Rec. Parameters.



<Rec.Parameters>
Freq.Range: 500Hz
Samp.Freq: X2.56
Rec.Time: Manual
Pre-Time: 0s
Voice: OFF(Marker)

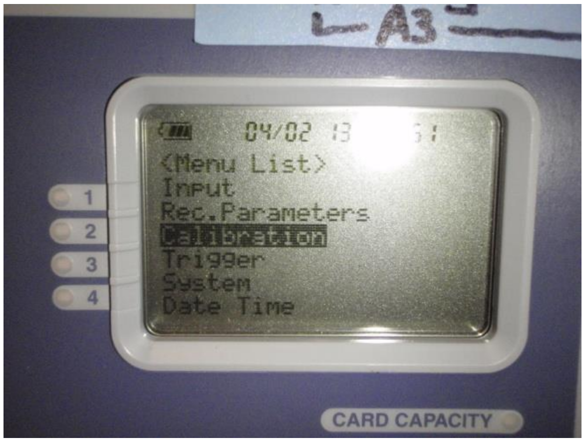


Frequency Range 500Hz
Sampling Freq. x2.56
Recording Time Manual
PreRec. Time 0s
Voice OFF(Marker)

1952MB [37:01:15] 2015/02/18 17:04:34

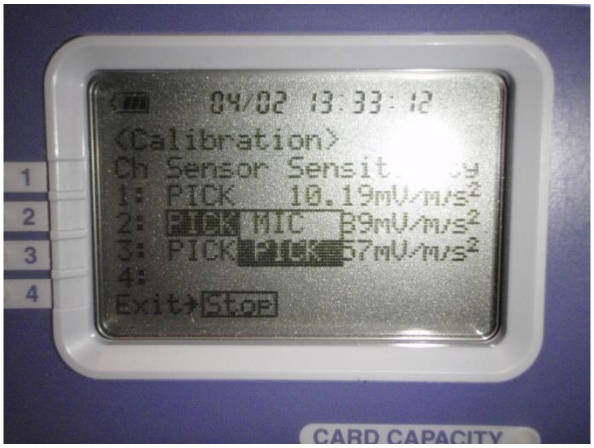
2.1 Make sure settings in Rec. Parameters are as follows: Frequency Range=500Hz, Sampling Frequency=x2.56, Recording time=Manual, Pre-Time=0s, and Voice=OFF:

2.2 Go back to MENU, choose Calibration: ***(DA-20 only)***



```
04/02 13
<Menu List>
Input
Rec.Parameters
Calibration
Trigger
System
Date Time
```

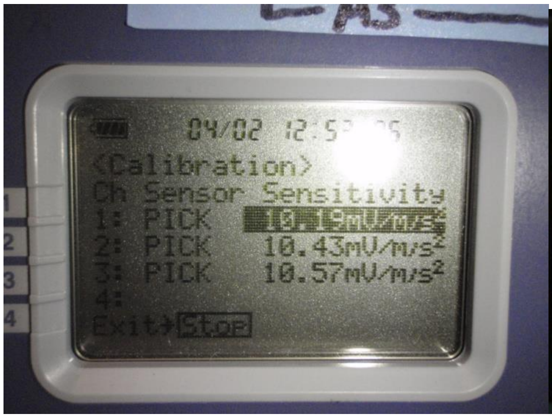
2.3 Change Sensor to PICK on all 3 channels. ***(DA-20 only)***



```
04/02 13:33:12
<Calibration>
Ch Sensor Sensit    ty
1: PICK   10.19mV/m/s²
2: PICK MIC   89mV/m/s²
3: PICK PICK  57mV/m/s²
4:
Exit→Stop
```

2.4 Look at the calibration grid (next page) for each accelerometer and ensure the sensitivity is correct for the attached accelerometer; in this case 10.19 mV/m/s^2

Put in the sensitivity for each channel. 1=x, 2=y, 3=z.



```
04/02 12:5
<Calibration>
Ch Sensor Sensitivity
1: PICK   10.19mV/m/s²
2: PICK   10.43mV/m/s²
3: PICK   10.57mV/m/s²
4:
Exit→Stop
```

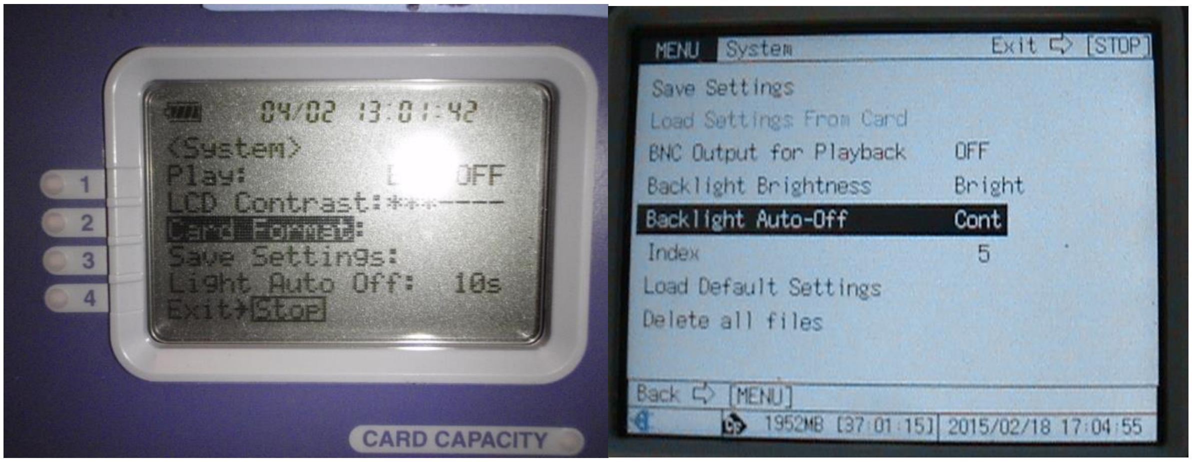
```
MENU  Input                          Exit ⇨ [STOP]
CH  Input  HPF  LPF  Sens  Sens  +  ty
 1  CCLD   OFF  OFF  PICK  1.02 +01  mV/(m/s²)
 2  CCLD   OFF  OFF  PICK  1.04  -   mV/(m/s²)
 3  CCLD   OFF  OFF  PICK  1.01E+01  mV/(m/s²)
 4  CCLD   OFF  OFF  PICK  1.02E+01  mV/(m/s²)
 5  CCLD   OFF  OFF  PICK  9.89E+00  mV/(m/s²)
 6  CCLD   OFF  OFF  PICK  1.03E+01  mV/(m/s²)
 7  OFF    OFF  OFF  OFF
 8  OFF    OFF  OFF  OFF
Back ⇨ [MENU]  Copy ⇨ [PLAY]
1952MB [37:01:15] 2015/02/18 17:04:24
```

Here is a list for all sensitivities for all accelerometers and all axes:

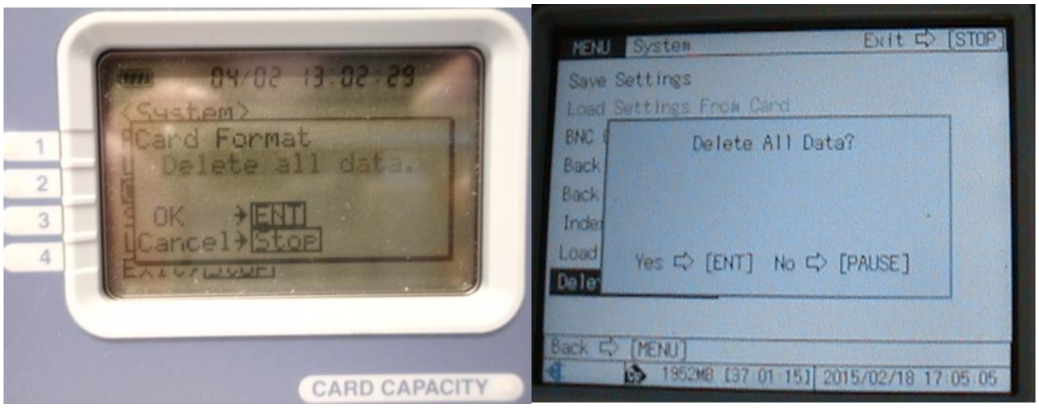
Accelerometer	**X**	**Y**	**Z**
1	10.31	10.33	9.63
2	10.24	10.37	10.11
3	10.19	9.89	10.35
4	10.11	10.14	10.11
5	9.88	10.15	9.89
6	10.51	10.64	10
7	10.1	10.11	9.99
8	10.18	10.22	9.93
9	9.89	10.32	10.52
10	10.36	9.86	10.11
11	10.20	10.43	10.27
12	10.29	10.31	10.36
14	10.10	10.50	10.06
S1	-	-	10.32
S2	-	-	10.74
S3	-	-	10.2
S4	-	-	10.43
S5	-	-	10.57
S6	-	-	10.25

Change the sensitivity on all channels.

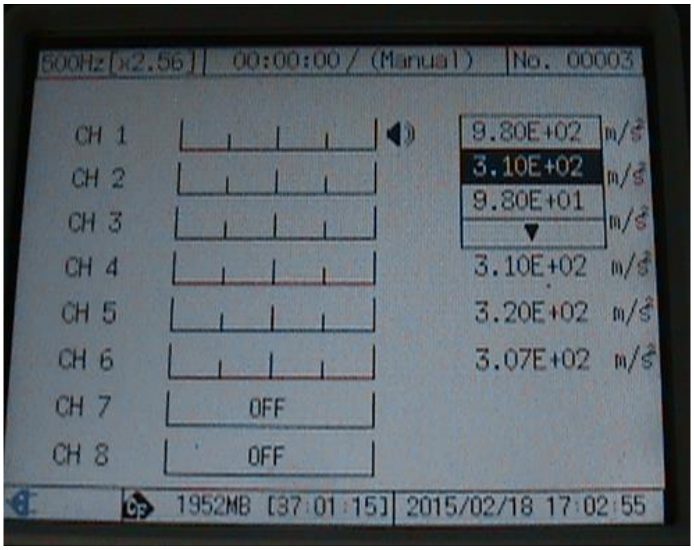
3.0 Go to MENU. Choose System, then Card Format



3.1 You get a warning that you are deleting all the data on the memory card. Unless you have data left on card that you have forgotten to transfer to computer, choose OK.



4.0 On the main screen, press RANGE. Adjust for all active channels to approximately 3 x 10^2 m/s^2 – this corresponds to 3V.


500Hz [x2.56] 00:00:00 / (Manual) No. 00003

CH 1 9.80E+02 m/s²
CH 2 3.10E+02 m/s²
CH 3 9.80E+01 m/s²
CH 4 3.10E+02 m/s²
CH 5 3.20E+02 m/s²
CH 6 3.07E+02 m/s²
CH 7 OFF
CH 8 OFF

1952MB [37:01:15] 2015/02/18 17:02:55

The RION settings are now ready.

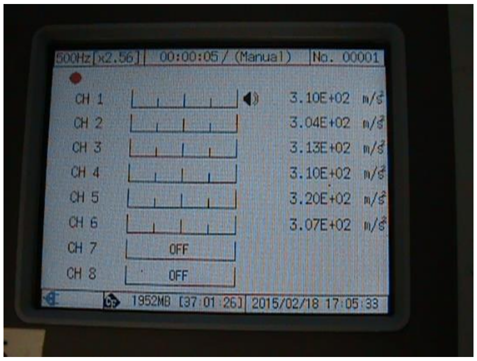
To Start A New Measurement:

5.0 Go through steps above to ensure settings are correct. Attach external battery and secure cable to Rion with a short strip of duct tape.

5.1 Place the seatpad accelerometer and feed cables through the seatback/seatpan joint before connecting to the Rion.

5.2 Place floor accelerometer on floor near seatpad accelerometer and connect cable to Rion. If dusty/greasy, wipe first with Chlorox Wet Wipe.

5.3 Press Record. You should see a flashing red dot on the screen and the Record button should have a flashing red dot near it.



```
500Hz [x2.56] | 00:00:05 / (Manual)   | No. 00001
●
CH 1                    3.10E+02  m/s²
CH 2                    3.04E+02  m/s²
CH 3                    3.13E+02  m/s²
CH 4                    3.10E+02  m/s²
CH 5                    3.20E+02  m/s²
CH 6                    3.07E+02  m/s²
CH 7      OFF
CH 8      OFF
         1952MB [37:01:26] 2015/02/18 17:05:33
```

5.4 **QC Procedure**

5.4.1 Move seatpad accelerometer away from you then towards you 3x, then move towards your right then to your left 6x, followed by moving it first up then down 8x.

5.4.2 Move floor accelerometer away from you then towards you 3x, then move towards your right then to your left 6x, followed by moving it first up then down 9x. If only z-channel, not a triaxial accelerometer, only the last step (up then down 8x) is necessary.

5.5 Tape down seatpad accelerometer with painters or gaffers tape.

5.6 Secure Rion in case behind passenger seat (daycab), driver seat (sleeper cab), or other location where it will be secure and where accelerometer cables are not stretched tight.

5.7 Use duct tape and/or Velco to securely attach external battery to leg of passenger seat or similar location.

5.8 Take photos of seatpad and floor accelerometer and any noteworthy features of cab.

5.9 Turn on GPS and use duct tape to securely attach to dash on passenger side. If dash is dusty/greasy, use Chlorox Wet Wipes first.

5.10 Record RION number, seatpad and floor accelerometer and cable numbers, GPS number, and times turned on on summary sheet. Record truck number, odometer reading, seat type, and any other pertinent details about truck, driver, seat, or trip on summary sheet along with time expected back.

Retrieval:

6.1 Remove GPS and turn off. Record time off on summary sheet. If GPS showing no lights or showing a red light, record that information on summary sheet.

6.2 Remove Rion logger case and ensure Rion still on and has a red flashing light on display indicating it is recording. Press STOP, wait for warning message to go away, then turn OFF. Record time off on summary sheet. If Rion already off, check if battery still plugged in and record information on summary sheet.

6.3 Disconnect accelerometer cables from Rion. Remove seatpad and floor accelerometers.

6.4 Record odometer mileage on summary sheet with any other pertinent information mentioned by driver.

Data Uploading:

7.0 Eject memory card from Rion and use a compact flash reader to connect the card to computer. Open the device the same way you would an external hard drive. Open the WAVE folder and copy the file to its new location on the hard drive. Change the file name to match the filename structure used such as STUDY_SUBJECT#_TIMEPOINT_TRUCK#_RION#_DATE. Eject memory card and replace in Rion. Deleting files off the memory card using the computer can result in card format errors when using the Rion.

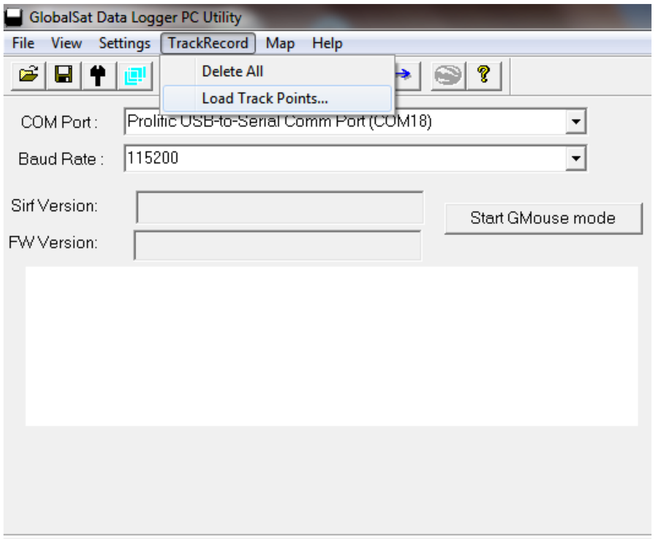
7.1 To quickly check Rion data, open the Rion DA-40 Viewer software and open the file. Go to Settings->File Info to check for issues with Rion recording settings. Go to Settings->Scaling Info to check for issues with sensitivity settings for the accelerometers. Go to Settings -> Graph Settings and change Freq. Weighting to Wd for x and y channels and Wk for z channels. Change Scaling to Auto or to Manual (setting Upper value to 5 and Lower value to -5 will show you most of your data). From here you can focus in on certain segments of the data using the second from the left graph icon beneath Edit. To see summary values, go to Calculate -> Statistical Values. Do not place too much weight on these summary values.

8.0 Turn the GPS on and connect to the computer. For the DG100, the built-in USB cord goes straight in. For the DG200, connect a USB-to-MicroUSB cord to use it. For the Qstarz, connect a USB-to-USB cord to use.

DG100: Open Data Logger PC Utility.

A1.0. If it asks “Do you want to configure the device at the first time”, answer No.

A1.1 Go to TrackRecord → Load Track Points…



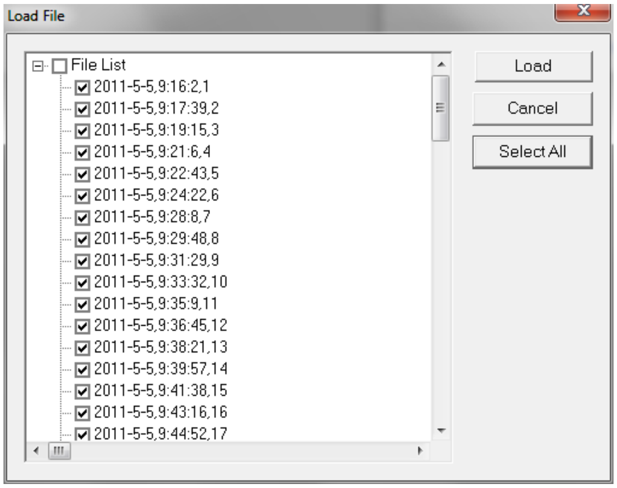
COM Port : Prolific USB-to-Serial Comm Port (COM18)

Baud Rate : 115200

Sirf Version:

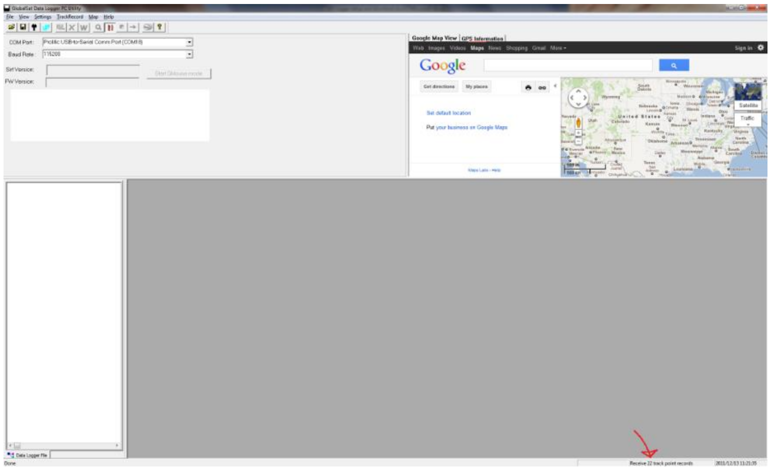
FW Version:

A1.2 Click Select All and then click Load.



☐ File List
- ☑ 2011-5-5,9:16:2,1
- ☑ 2011-5-5,9:17:39,2
- ☑ 2011-5-5,9:19:15,3
- ☑ 2011-5-5,9:21:6,4
- ☑ 2011-5-5,9:22:43,5
- ☑ 2011-5-5,9:24:22,6
- ☑ 2011-5-5,9:28:8,7
- ☑ 2011-5-5,9:29:48,8
- ☑ 2011-5-5,9:31:29,9
- ☑ 2011-5-5,9:33:32,10
- ☑ 2011-5-5,9:35:9,11
- ☑ 2011-5-5,9:36:45,12
- ☑ 2011-5-5,9:38:21,13
- ☑ 2011-5-5,9:39:57,14
- ☑ 2011-5-5,9:41:38,15
- ☑ 2011-5-5,9:43:16,16
- ☑ 2011-5-5,9:44:52,17

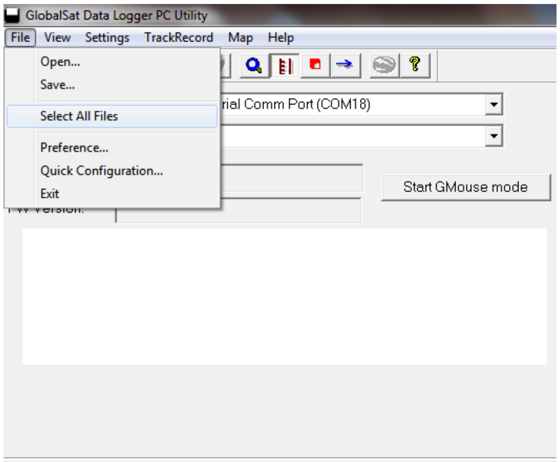
A1.3 It will show the progress in the bottom right corner – it may take several minutes if a full shift was recorded.



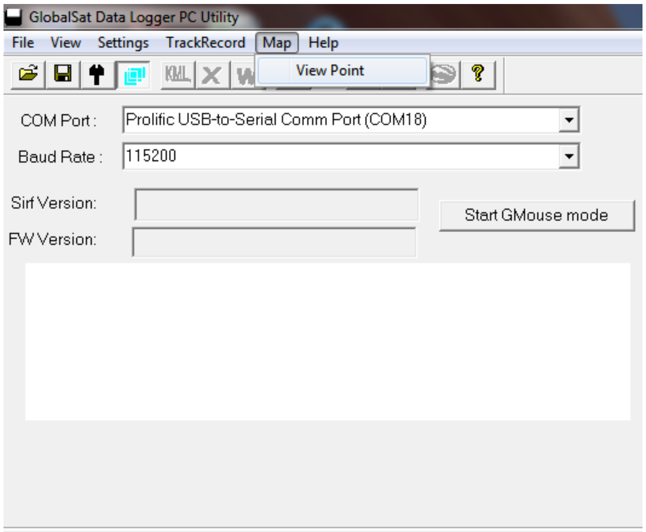
Receive 22 track point records

2011/12/13 11:21:35

A2.0 When the software is done downloading files, Go to File → Select All Files



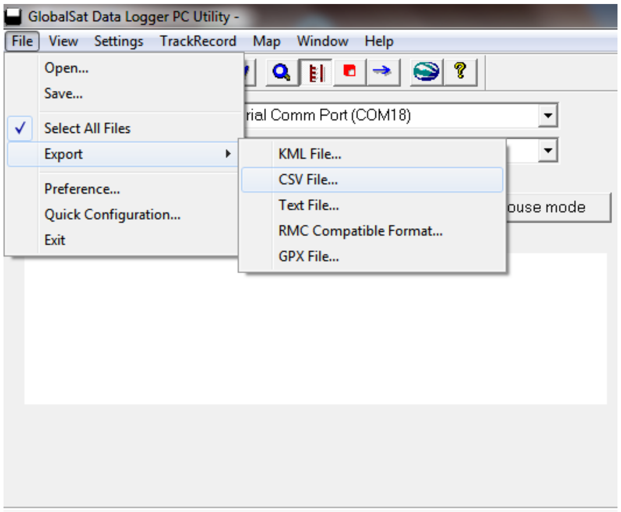
A2.1 Go to Map → View Point



COM Port : Prolific USB-to-Serial Comm Port (COM18)

Baud Rate : 115200

A2.2 Go to File –> Export → CSV File…



A2.3 Change the file name to match the filename structure used such as STUDY_SUBJECT#_TIMEPOINT_TRUCK#_GPS#_DATE and click Save. Repeat for KML and GPX. Take a screenshot of the map and save with a similar name structure.

A3.0 Go to TrackRecord -> Delete All and select Yes.

DG200: Open GlobalSat – DG – 200 Tool.

B1.0 Select Serial Port at the top. On the left, check DG – 200 Data Logger.

B1.1 At the top, select the green arrow.

B1.2 Go to File -> Save and select CSV. Change the file name to match the filename structure used such as STUDY_SUBJECT#_TIMEPOINT_TRUCK#_GPS#_DATE and click Save. Repeat for KML and GPX. Take a screenshot of the map and save with a similar name structure.

B1.3 Select the red 'X' at the top and confirm Yes to delete all points.

Qstarz: Open Qstarz Data Viewer.

C1.0 Select Read from Device and check the dates and times corresponding to your measurement.

C1.1 Select Save to file and change the file name to match the filename structure used such as STUDY_SUBJECT#_TIMEPOINT_TRUCK#_GPS#_DATE and click Save. Repeat for KML and GPX.

C1.2 Select Show on Map. Take a screenshot of the map and save with a similar name structure.

C1.3 Select Erase device.

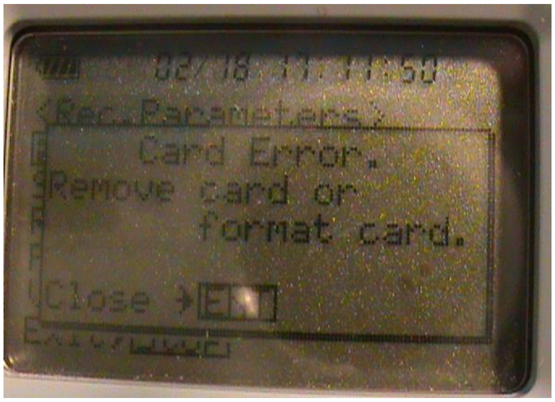
11.0 Connect GPS to USB power and allow to charge. Connect external battery to battery tender; battery will be fully charged when battery tender indicator light is green. Recharge internal batteries.

12.0 Backup GPS and Rion files to Idrive and/or external hard drive.

Troubleshooting

1. **Card Error Warning Message**:

Rion displays warning message shown below or shows warning message of No Card:



02/18 11:11:50

<Rec.Parameters>

Card Error.
Remove card or
format card.

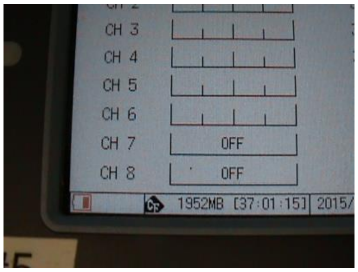
Close →

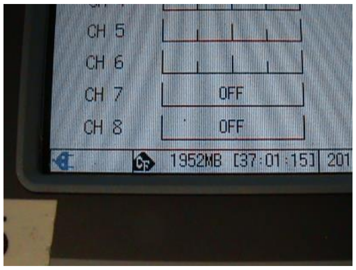
Go to Menu -> System and select Format Card and press Enter. If warning message is repeated, follow steps below to eject card:

On upper right edge, press outwards to open memory card slot. Press the black trigger to the right inwards to eject the memory card. Memory card should be Extreme CompactFlash. For the DA-20, the memory card must be 2 GB. For the DA-40, it can be either 2 or 4 GB.

2. **Rion turns on then abruptly turns off or shows warning message about CCLD:**

Insufficient power – the icon in the lower left corner of the display will resemble a blue battery when running off internal battery, will resemble a plug when using external power, and will turn red when battery power is low. Connect Rion to fully charged external battery and if possible change internal batteries. For DA-20 NiMH rechargeable AAs do not have sufficient voltage to run CCLD so the Rion will change its settings but may still show the battery indicator as blue. To prevent this, plug the DA-20 into external power prior to powering on. Higher voltage (1.6V) NiZn AA batteries can be used in the Rions as a backup to external battery power.

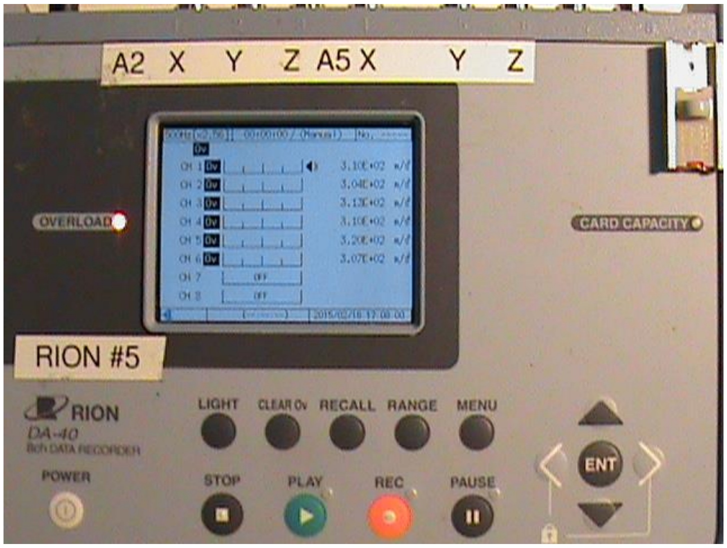




3. **Rion shows units other than m/s^2 in Range on front screen:**

Sensor has changed to mode other than PICK. Redo step 2.3 for DA-20 or step 1.2 for DA-40. Go through steps to check settings in case other settings have changed.

4. **Overload light stays on during QC procedure:**



Check RANGE by doing step 4.0. The overload warning light will come on as accelerometers are initially connected but will go away within a few seconds. While it might reappear if someone sits on the seat pad or a similarly large motion occurs, it should not appear during the QC procedure.