Intervening in the Transportation Sector to Reduce Driver Fatigue, Low Back Pain, Discomfort and Increase Vehicle Safety

Final Report

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Research Team

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To Cite this Report

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EXECUTIVE SUMMARY

Introduction

Truck drivers work long hours and are exposed to whole body vibration (WBV) that puts them at increased risk for back injury, fatigue and potentially increase risk of crashes. Over the past few years there has been increased concern over the impacts of WBV on driver health as new and sophisticated studies have strengthen the links between WBV exposures and these health and safety impacts. Additionally, new seating systems involving electromagnetically active (vibration cancelling) technologies are now on the market and have the potential to reduce truck drivers' exposures and resultant health impacts. The overall goals of this study were (1) to make a contribution to the evidence for the link between the use of electromagnetically active seating, reduced exposures, and health effects, (2) to gather and summarize evidence that could be used by stakeholders in the trucking industry to make decisions on reducing drivers' vibration exposures, and (3) to understand the decision-making process of drivers and companies regarding the adoption of an innovation that reduces drivers' WBV exposures.

Methods

To accomplish these goals the research was designed to use multiple and mixed research techniques including biomechanical and vibration measurements, surveys, webinars and qualitative semi-structured interviews. Phase 1 of the study focused on gathering evidence on the vibration transmission characteristics of existing seats (field study) as well as, through a laboratory study, industry standard passive and active suspension seats. Additionally, we conducted a document analysis where we reviewed the peer reviewed as well as the grey literature to identify highly relevant sources of evidence pertaining to truck drivers' exposures to WBV and possible health effects as well as potential strategies for exposure reduction. It was thought that such information, if made available to drivers, companies and other stakeholders, would inform decision-making regarding vibration that would potentially reduce drivers' exposures.

Phase 2: This phase of the study focused on the knowledge that managers and drivers have about the risks of WBV exposure and how vibration reduction fits with their overall priorities. We had an interest in what information would be useful for companies in incorporating the consideration of WBV in their purchasing decisions when they need new trucks or seats.

Findings

At total of 23 truck drivers from trucking companies based in Winnipeg completed all aspects of the field data collection included in cab measurements of WBV, completion of interviews and surveys. Visual representations of road segments by WBV level were developed that showed which roads made the biggest contribution to drivers' overall daily vibration exposure. Amplitudes of Z-axis exposures were highest for jobsite and rural roads but overall drivers' WBV exposures did not exceed the ISO 2631-1 Health Guidance Caution Zone.

The laboratory findings provided evidence that the electromagnetically active seating was effective in reducing Z-axis WBV in truck drivers. There were no significant reductions in exposures for the electromagnetically active seating in the X and Y-axis exposures.

Interviews with truck drivers found that they were generally not overly concerned about vibration exposures. Although a number of drivers in the field study in Manitoba and drivers recruited at truck stops reported musculoskeletal pain and discomfort none attributed this to WBV. Most felt the pain was part of the job and due to prolonged sitting, lifting, or aging. Most drivers had trucks less than 5 years old and reported that the existing seats were comfortable. Most drivers recruited at the truck stops were unaware of electromagnetically active seating and worried about the cost. Although stakeholders were interested in learning more about WBV and truck driver's health we were unable to provide evidence that would support a business case for adoption especially for small and mid-sized carriers. Lost time injuries are fairly rare events for small and medium sized

carriers and, with it being difficult to attribute a musculoskeletal disorder to WBV, the business case for the new technology is a challenge.

Recommendations

Further WBV exposure and health studies in truck drivers are needed to build the evidence base. Additionally, larger intervention studies looking at the effectiveness of electromagnetically active seating and driver health are important especially if they include a cost-benefit analysis. More research is needed in the area of vigilance and WBV exposures in truck drivers as it had been suggested that exposures below the Health Guidance Caution Zone may decrease vigilance and increase crash risk. Most drivers and managers in trucking firms appear to not be concerned about WBV exposures so efforts should be taken to highlight the health risks and also the benefits of reducing exposures.

2 Context: Vibration in trucking and impact on health of drivers

Professional truck drivers are required to sit in their trucks for long hours. They are at risk for the development of a number of adverse health conditions that include back pain, other musculoskeletal disorders, cardiovascular disease, sleep disorders, and fatigue that has been linked to increased crash risk. Prolonged sitting, whole-body vibration (WBV), and poor posture in truck drivers have been shown to be correlated with many of these adverse health effects. The primary objective of this study was to investigate approaches to reduce the exposure of truck drivers to WBV, which in turn has the potential to improve the health and wellness of drivers. A secondary objective was to learn about the facilitators and barriers for trucking firms and drivers in taking action to reduce WBV exposures.

2.1 Whole body vibration (WBV) exposures

WBV is the oscillation of a person about a fixed point and occurs in vehicles such as tractors, trucks, earth-moving machinery, mine and quarry equipment, and aircraft. WBV is categorized into:

- sinusoidal vibrations are oscillations that repeat over time at a constant frequency and amplitude (e.g., an out-of-balance vehicle tire);
- periodic vibrations are the combination of two or more sinusoidal vibrations;
- random vibrations are oscillations which do not repeat themselves (e.g., driving on a bumpy road); and
- transient vibrations occur for a short time (e.g., driving over a pot-hole).

Generally, truck drivers – both long or short haul – experience a combination of periodic, random and transient vibrations (Du, 2016).
Drivers may be exposed to vibration from a number of directions and standard practice is to measure vibration in the three planes:

- x (back and forth);
- y (side to side);
  and
- z (up and down).

Another characteristic of WBV is frequency which is the rate of oscillations in a time period, usually measured in cycles per second or hertz. A final characteristic of vibration is its intensity which is the rate of change in the speed of the movement or acceleration. The acceleration is measured in meters per second squared. These three characteristics of vibration – direction, frequency, and intensity are important in the assessment of health effects. Finally, duration of exposure is important in assessing the potential health impacts of WBV and can be measured in seconds, minutes, hours, or years. Considerable research has been conducted regarding the human health effects of WBV and common measures of vibration characteristics are important to assess risk. These are:

1) the frequency-weighted root mean square (RMS) acceleration (Aw); The Aw describes the average intensity of the vibration over the collection period; however, it is not time-normalized and thus not the favourable metric to compared WBV exposures of different durations.
2) the eight-hour equivalent frequency-weighted RMS acceleration (A(8)); The A(8) is normalized to eight hours of WBV exposure (regular work shift) but will underestimate WBV exposure if there are high peaks and jarring.
3) the vibration dose value (VDV). The VDV is a measure of vibration dose over a time period, typically 8 hours (VDV(8). VDV is more sensitive to high peaks and jarring and it accounts for the cumulative WBV exposure transmitted to the body for the day (Du, 2016).

In assessing WBV, the above measures are calculated, applying appropriate frequency weightings for each of the X, Y, and Z axes (see Figure 2). The aforementioned measures (Aw; A(8); VDV(8)) for the predominant axis are compared to the vibration guidance values to assess health risk (Du, 2016).

2.2 Truck Drivers' Exposure to WBV

A number of factors influence truck drivers' exposures to WBV. These include road surface conditions, vehicle weight and type, cab suspension, vehicle speed, driving characteristics, and seat types (Johanning *et al*., 1991, Ozkaya *et al*., 1994, Piette & Malchaire, 1992, Village *et al.,* 2012;). A review of the strategies to reduce WBV exposure in drivers found that alteration of the following factors was effective in reducing the magnitude of WBV: seat type (with/without backrest), seat and cabin suspension, as well as the weight and posture of the driver (Tiemessen, 2007). A seat that utilizes electromagnetically active (EM-active[1]) seat-suspension technology is now on the market. This technology uses sensors to detect vertically induced seat motion which is reduced by activating a linear actuator in the seat. EM-active seats reduce WBV exposure in the z-axis by up to 55% while the typical air ride (passive air suspension) seats attenuate only about 5% of the WBV (Blood *et al*., 2012).

There are no regulations in Canada that directly reference WBV exposure levels and recommend exposure limits. The Manitoba Workplace Safety and Health Act and Regulation requires that an employer not place any machine in a workplace that may cause vibrations that would pose a risk to the safety or health of employees. In many other provinces there is no mention of vibration in their OHS regulations. Despite having no formal regulations, Canadian agencies usually follow the limit values recommended by the International Organization for Standardization 2631-1 (ISO 2631-1) "Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration" (published in 1997). The American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for whole-body vibration and they also reference ISO 2631-1.

There is a considerable body of literature regarding the health effects of whole-body vibration. The US National Institute for Occupational Safety and Health (NIOSH) produced a comprehensive review of literature published between 1971 and 1984 and reported exposures to WBV affects the cardiopulmonary, cardiovascular, musculoskeletal, metabolic, endocrine, gastrointestinal, and nervous systems of the body (NIOSH as cited in Cann 2002). Subsequent research has supported NIOSH's conclusions and have also found that adverse impacts on the reproductive system, muscle function (fatigue), back injury (thinning intervertebral discs, herniation, spine degeneration) and pain, and vigilance (cognitive fatigue) (Cann 2002, Mansfield 2005).

The Second Edition of ISO 2631-1, *Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-body Vibration* recognizes the complexity of the human physiological, pathological as well as behavioural responses to whole body vibration. The goal of the standard is to define methods of quantifying and provide guidance for WBV exposures in relation to (1) human health and comfort, (2) the probability of vibration perception, and (3) the incidence of motion sickness (ISO, 1987). For truck drivers the primary concern is vibrations within the frequency range of 0.5 to 80 Hz for which there is the potential for effects on health and comfort (note that the frequency range for motion sickness is 0.1 to 0.5 Hz).

The figure below provides the resonant frequencies for various parts of the human body. Exposures to vibration that contain these resonant frequencies are particularly harmful as they magnify the amount of movement in the structures of the body (in physics this is described as small periodic driving forces have the ability to produce large amplitude oscillations at resonant frequencies – think of the tuning fork demonstration in science class). In setting their guidance for ISO 2631-1, the authors considered the available experimental and epidemiological evidence in developing frequency weightings for the standard (see Figure 2; note that Wk(z) is the curve for the Z-axis with the other curve applicable to the x and y axes). Looking at the power spectral density of vibrations at the seat top of a long-hauls truck shows that much of the vibration energy is between 1 and 10 Hz (Johnson, 2019 personal communication; Louwers, 2016).

[1] Also termed electromagnetically active vibration cancelling (EAVC)

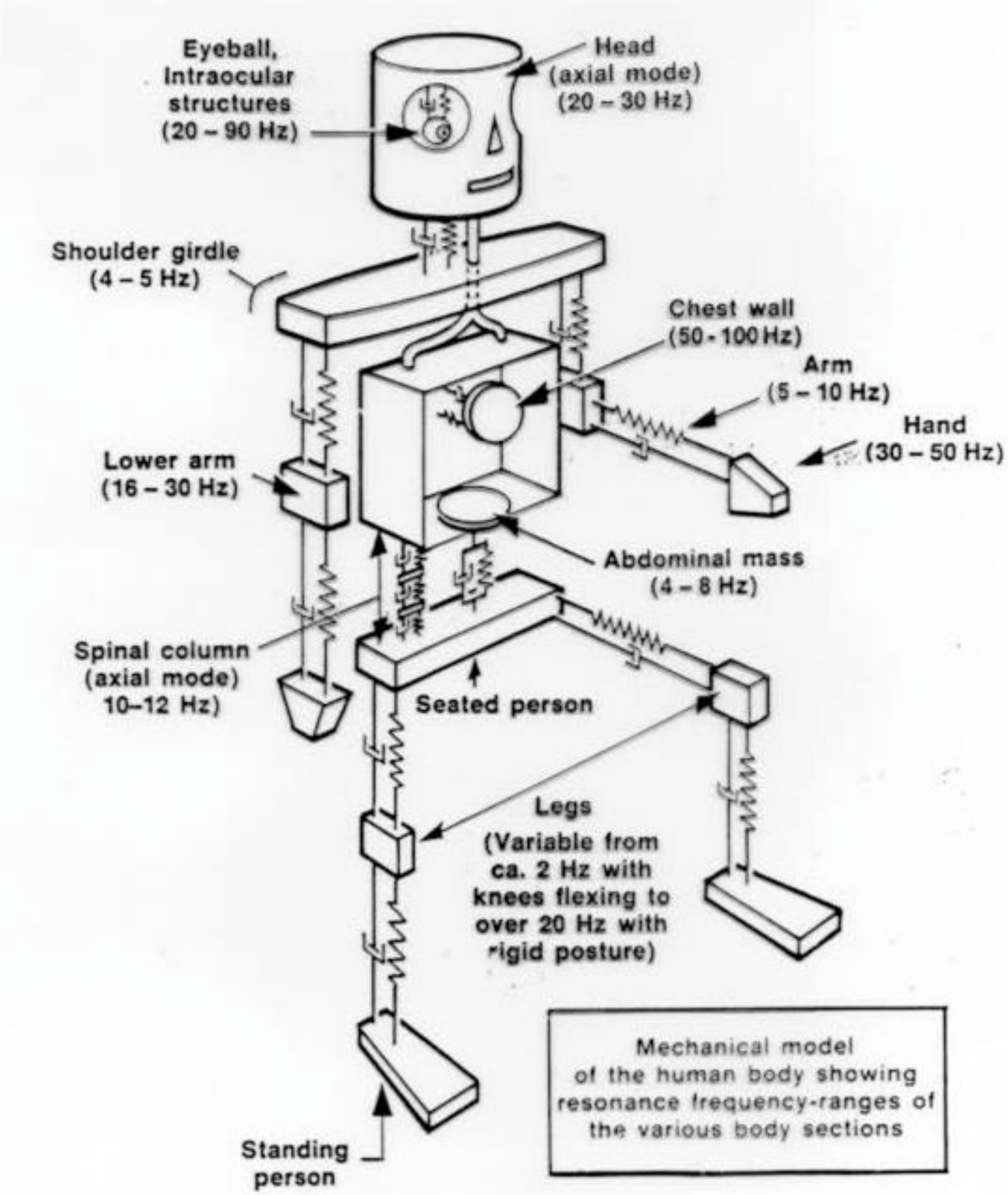


Figure 2.1 Image From: http://physics.stackexchange.com/questions/
https://physics.stackexchange.com/questions/37543/does-the-human-body-have-a-resonant-frequency-if-so-how-strong-is-it/37916#37916

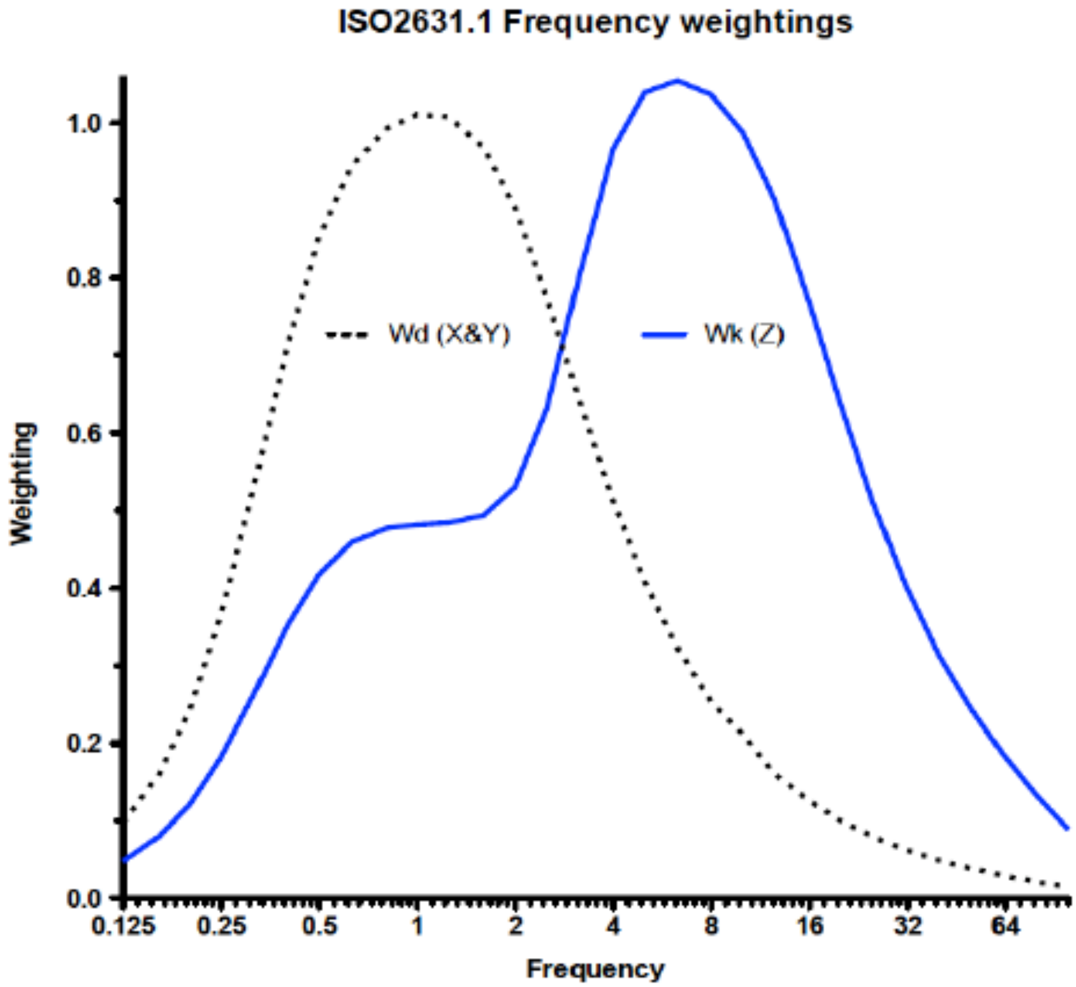


Figure 2.2 ISO 2631 Weighting Curves

ISO 2631-1 provides guidance for continuous WBV exposures over periods from 1 minute to 24 hours. They define a Health Guidance Caution Zone for which exposures above the zone are likely to result in health risks and below the zone health effects have not been clearly documented or observed. The values are shown in Table 1 show the action limit (the lower end of the Health Guidance Caution Zone) and the exposure limit with is the upper limit of the Health Guidance Caution Zone.

Table 2.1 International Organization for Standardization (ISO) 26531-1 Health Guidance Caution Zones for whole-body vibration exposure.

	ISO 2631-1	
	A(8) (m/s^2)	VDV(8) ($m/s^{1.75}$)
Action Limit	0.5	9.1
Exposure Limit	0.8	14.8

Although Canadian regulatory agencies have no specific guidance on occupational exposures to WBV they typically recommend use of ISO 2631-1 and their Health Guidance Caution Zones. The Canadian Centre for Occupational Health and Safety (CCOHS) states that "it is prudent to reduce the level of exposure as much as practical since vibration causes ill health effects" (CCOHS, 2008). This more precautionary approach of the CCOHS makes sense as more recent studies are providing evidence that adverse health effects are occurring at lower exposure levels and that the action limit for WBV may be too high (Kim et al., 2016).

There are three ways to reduce the whole-body vibration in long-haul truck tractors:

- improve chassis suspension,
- improve truck cab vibration isolation, and
- improve or install seat suspensions to isolate the driver from motion of the cab floor.

At the seat level, there are two ways that seat suspensions can reduce WBV from the floor. Seat designers can use passive and active motion reduction techniques.

Passive control devices have no feedback capability between the seat and the floor. Passive control devices are the least costly and currently the most popular. Common passive seats that are commonly used in the long-haul trucking industry is the "air ride" suspension system. In the air ride system, an air bag is used to act like a mechanical spring when inflated and when combined with a damper, the air ride seats can reduce the WBV level when compared to other passive systems consisting of mechanical springs and rubber padded seats. Active vibration isolation employs electric power, sensors, actuators, and control systems. Active control devices incorporate real-time WBV recording instrumentation on the cab floor and depending on the input vibration magnitude and frequency, the system's processing equipment and actuators within the structure produce forces in an equal and opposite fashion to the forces of the external vibration. Studies conducted by Blood et al. (2010; 2015) demonstrated that an active suspension seat can significantly reduce the WBV levels when compared to passive seat designs.

There is growing awareness about the effects of whole-body vibration exposure in truck drivers and the need to take steps to reduce exposures. With this in mind the study team felt that the time was right to conduct this investigation. The overall objective of this study was to reduce the exposure of truck drivers to whole body vibration (WBV), which in turn has the potential to reduce fatigue, low back pain and disability as well as collision risk. The study objectives were to be accomplished through a two-phase study – (1) documenting vibration exposures and developing the evidence base[2] to better inform decision-making, and (2) understanding the decision-making process for health innovations in the trucking sector and transferring knowledge about health risks to key stakeholders who could take action to reduce exposures.

[2] Originally we had planned to conduct a cost-benefit analysis for the implementation of active suspension seats within a number of trucking companies. However, our initial field and laboratory studies showed that most drivers' exposures were not within the Health Guidance Caution Zone with their existing equipment; thus, the implementation of active suspension seats, although reducing WBV exposures, may not have substantially impacted drivers' health in ways that could be assessed in a study with small to moderate sample size.

3 STUDY METHODS

This research had multiple goals which included:

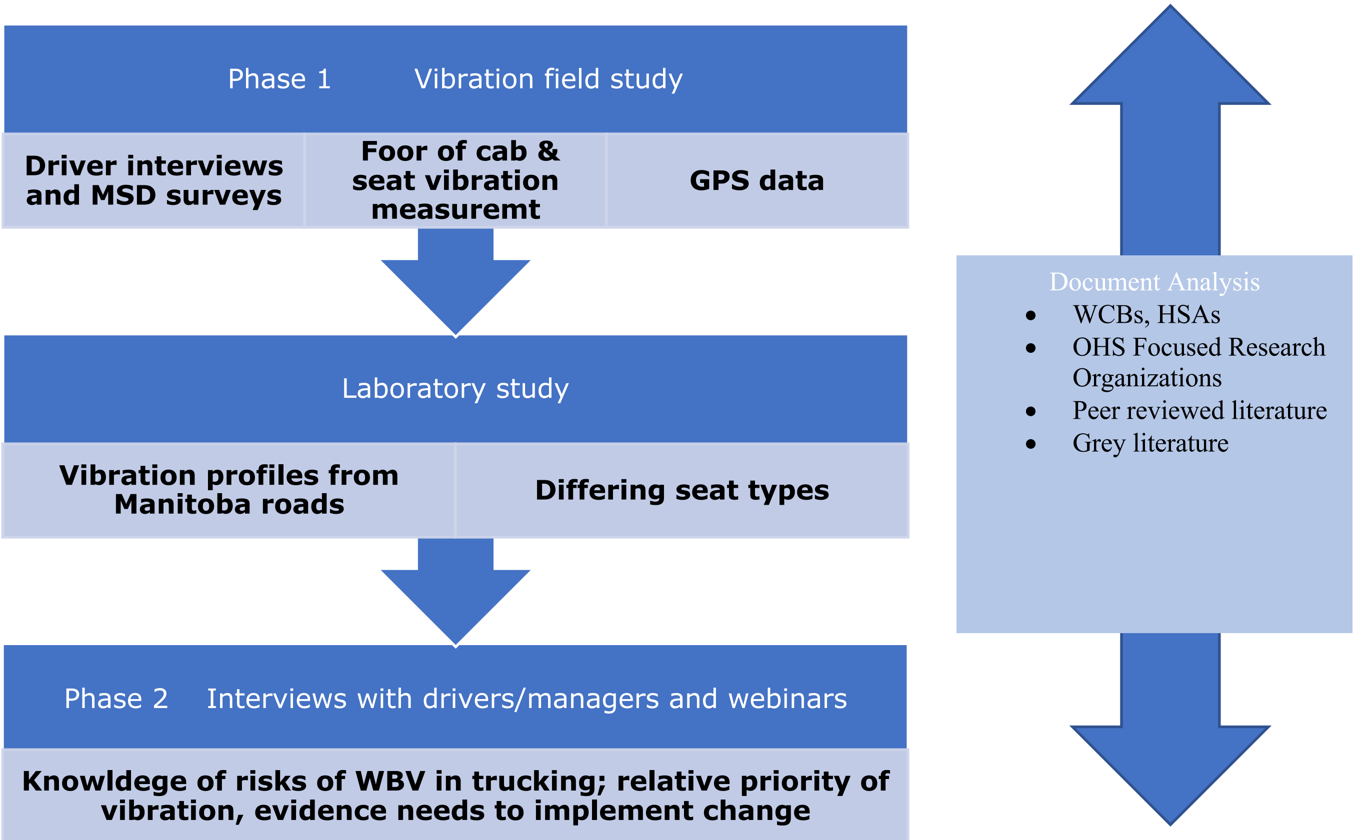
- the gathering of evidence on the vibration transmission characteristics of typical active and passive suspension seats (Phase 1),
- the facilitation of the transfer of knowledge and the assessment of the knowledge translation (KT) effort and the investigation of decision-making processes of drivers/companies regarding the adoption of an ergonomic innovation (Phase 2).

To accomplish these goals the research was designed to use multiple and mixed research techniques including biomechanical measurements, surveys, webinars and qualitative semi-structured interviews. Phase 1 of the study focused on gathering evidence on the vibration transmission characteristics of existing seats (field study)as well as, through a laboratory study, industry standard passive and active suspension seats. Additionally, we conducted a document analysis where we reviewed the peer reviewed as well as the grey literature to identify highly relevant sources of evidence pertaining to truck drivers' exposures to WBV and possible health effects as well as potential strategies for exposure reduction. It was thought that such information, if made available to drivers, companies and other stakeholders, would inform decision-making regarding vibration that would potentially reduce drivers' exposures.

Phase 2 of the study focused on the knowledge that managers and drivers have about the risks of WBV exposure and how vibration reduction fits with their overall priorities. We had an interest in what information would be useful for companies in incorporation the consideration of WBV in their purchasing decisions when they need new truck or seats.

Figure 3.1 provides an overview of the data collection strategies for the two phases of the project.

Figure 3.1 Data collection strategy



3.1 Phase 1: Gathering evident to support decision making

3.1.1 Field study of vibration exposures

We recognize that there are a variety of truck seats on the market and that each seat's attenuation properties vary with the cab in which it is mounted and the road surface (Dickey et al, 2016). The attenuation values generally correspond to the overall design category of the seat, being one of: passive with an air suspension system (air ride) and active vibration cancelling system. Interviews with trucking companies and truck drivers were conducted to identify the most frequently purchased brands and models of seats in each of the two categories. Attenuation properties of seats that were considered representative of the two categories were determined through a combination of field-testing experimental studies, and evaluation of previous studies. Cab vibration measurements of a variety of trucks in field conditions were performed to obtain vibration profiles for the different types of trucks. The field study was conducted on trucks travelling over Provincial Trunk Highway 75, the Trans-Canada highway as well as some urban and rural roads in the Winnipeg area. Vibration profiles of the trucks were replicated and detailed analyses of the vibration attenuation characteristics of representative seats were be performed using a multi-axis motion platform at Western University in London, ON.

Field vibration measurements
Truck drivers were asked to allow a research associate to measure cab vibration while they drove to their next destination. Drivers were offered a cash card of $15 that was redeemable at a truck stop chain. After completion of the participant consent form, the drivers were asked questions about his/her seat and truck. Details of both the tractor (manufacturer, model, suspension, age, mileage), trailer (manufacturer, load), and seat (manufacturer,

model) were obtained. The research associate followed the truck driver in their own vehicle during data collection. At the end of the data collection period the driver participated in a brief interview.

In accordance with the ISO standard, a triaxial accelerometer was mounted to the top of the truck operator's seat pad and a second triaxial accelerometer was mounted to the floor of the truck's cab beneath the driver's seat. Raw acceleration data was recorded at 500 Hz using an eight channel datalogger (DataLOG II P3X8, Biometrics, Gwent, UK). Data was collected for the duration of the drivers shift.

Vibration path selection and production

Geographical position, speed, and time of 33 long-haul trucks were recorded at 1 Hz using a GPS tracker (Model DG-100; GlobalSat, Chino, CA, USA). The type of road that the trucks were travelling on was determined by analyzing the geographical position of the trucks using Google Earth. The time spent on a given road type was noted and this time was cross referenced with the time on the data logger (DataLOG II P3X8, Biometrics, Gwent, UK) to determine which vibration records correspond to each road. Vibration records were then subdivided into 20 second segments. The 20 second segments were grouped by road type and then divided further by ranking the vibration exposure on each axis into tertials. Profiles were grouped by the rank of vibration in each axis. For example, a vibration profile with high vibration on all axes was ranked as 333 while a vibration profile with low vibration on axes X and Y and vibration in the second tertile on the Z axis would be ranked as 112. The frequencies of occurrence for all ranks of profiles for each road type were calculated. Then the top six most common ranks were noted for each road type for a total of 30 different ranking and road type combinations and a different 20 second segment with an average speed over 5 kph was selected to represent each of these combinations.

The 30 segments were vetted for erroneous data by filtering for raw mean acceleration above one m/s2 over the 20 seconds and a peak acceleration over 20 m/s2. None of the 30 segments were found to be above either of these thresholds. The accelerations of segments were high and low pass filtered with a second order Butterworth filter at 0.5 Hz and 20 Hz using LabView (v2012, National Instruments; Austin, TX, USA) resulting in each segment to have a vibration frequency range of 0.5 to 20 Hz. Raw acceleration data was down sampled from 500 Hz to 200 Hz using LabView as the motion platform cannot follow paths that are higher than 200 Hz. Accelerations were then double integrated to produce displacement data that created the path the motion platform would follow using LabView.

Interviews with participating drivers

Drivers who participated in the field vibration study were interviewed. All drivers who participated in the field study agreed to be interviewed and provided complete information.

After completion of the participant consent form, the drivers were asked just a few questions Details were obtained about the tractor (manufacturer, model, suspension, age, mileage), trailer (manufacturer, load), and seat (manufacturer, model, age). At the end of the workday the drivers were interviewed and completed a body comfort/pain questionnaire. This body map allows the respondent to report pain/discomfort in 16 body areas using a 5-point scale. The interview schedule is contained in the Appendix.

3.1.2 Controlled laboratory study

A component of Phase 1 of the investigation was the controlled laboratory study evaluating the vibration attenuation properties of commonly installed long-haul truck seats. This laboratory study took place after the field study and utilized actual vibration measurements obtained in trucks travelling on Manitoba highways and roads.

Vibration attenuation performance of suspension seats were tested by mounting seats to the top surface of a 6df motion platform (R3000, Mikrolar Inc. Hampton, NH, USA). Each seat's suspension was set to a height so that the participant's feet rested flat on the top of the motion platform. Participants were instructed to sit upright with their back in contact with the seat back and arm resting either in their lap or on the arm rests. Participants could adjust the arm rests to their liking, but the back-rest angle was set beforehand. The participants did not wear a seat belt.

An electromagnetic active vibration canceling (EAVC) suspension seat (Boseride, Bose corporation, Massachusetts, USA) and a passive suspension seat (Legacy Silver, Seats Incorporated, Wisconsin, USA) were tested. Both seats are designed to perform in a long-haul trucking vibration environment. Both seats were not modified from factory specification. Both seats' air suspension systems were filled by an air compressor at 120 psi. The Boseride seat was powered with a 15 V adjustable power supply that was adjusted to output 12 V DC. A triaxial accelerometer was placed on top the seat cushion and another was placed atop of the 6df motion platform underneath the seatpan accelerometer. Raw acceleration data was recorded at 500 Hz. Participants were exposed to 10 field exposure paths (2 paths selected at random without replacement of the 6 possible for each occupational exposure type) and nine random vibration paths (accelerations of 0.2, 1.0, and 1.5 m/s2 between 0.5 and 20 Hz). All field exposures were tested, then random vibration exposures were tested for the first seat. For the second seat the order was reversed as the random vibration exposures were tested before the field exposures. Order of the paths was randomized for each participant, but the order was the same for each seat. Both seats were tested in the same session so a second visit to the laboratory could be avoided in effort to curb participant drop out. The seat effective amplitude transmissibility (SEAT) in equation 1 was calculated for all axis using unweighted rms accelerations.

$$SEAT(\%) = \frac{Unweigthed\ rms\ accel_{!"\#\$}}{Unweighted\ rms\ accel_{\%\&\#!!'!}} x100 \quad (1)$$

Figure 3.1 Placement of accelerometers on the truck seat and cab floor

3.1.3 Document analysis

There is a tremendous, and indeed overwhelming, amount of information that has some degree of relevance to WBV exposures in truck drivers, health effects, and recommendations to reduce exposures. For example, there are hundreds of peer reviewed articles in the area of health effects of whole-body vibration. Most studies are in controlled environments or involve exposures not relevant to trucking. Our study team reviewed the literature and presents key articles that are about truck driver exposures/health effects or are highly relevant for drivers. Similarly, the grey literature which contains information from sources such as reports, guidance documents, best practice documents, videos, was searched and the materials felt to be most useful were reviewed.

3.2 Phase 2: Knowledge translation and understanding decision making

Phase 2 of the study focused on the facilitation of the transfer of knowledge about the importance of WBV for the health of drivers as well as practical approaches for reducing exposures. Our original plan was to provide data on the vibration characteristics of specific seats so that it would be possible to select seats that best fit the vibration characteristics of the trucks that the company owned. This approach turned out to be unfeasible because the attenuation values of different brands of air ride seats varied considerably making it difficult to predict how the seat would perform for a given truck. We were hoping to develop an evidence-based approach for selecting the most appropriate air ride seat for a given truck and then follow up with companies regarding their application of this knowledge.
The alternate approach that we took involved grouping of vibration data by suspension type (passive vs active) and developing recommendations based on these categories. We obtained data for typical passive suspension seats in the field study as well as the one available brand of active suspension seat (Bose Ride by Bose Corporation). Additionally, we conducted laboratory simulations using vibrations characteristics of roads in Manitoba to determine the attenuation values for one very typical air ride (Legacy passive suspension) seat and a Bose Ride seat. Findings and recommendations to reduce drivers' exposures were based on these findings. We took advantage of the contacts we made during the research. We conducted interviews which were semi-structed and focused on the factors that influenced purchasing decisions. Most of the interviews were not taped but the research team members kept notes of the responses. We conducted short interviews about health concerns and injury histories with 23 truckers who participated in our on-road measurements of vibration. We spoke to several employer managers about new seat purchase decisions. We had the opportunity to discuss claims histories and trucking issues with the Manitoba WCB managers responsible for the trucking industry. During our exploration of seating options, we discussed preferences with seat sales staff. Finally, we had an opportunity to discuss the issue of maintenance and seat preferences with a mechanic that serviced trucks for a large employer.

3.2.1 Conferences and webinar and participant feedback

Based on the document analyses as well as from quantitative and qualitative data obtained during the study, the research team developed teaching materials that were used in a webinar and presentations to industry and technical groups. The purpose of these presentations was to both present existing evidence from the literature related to WBV in trucking and approaches to prevention but also to discuss study findings. In all the sessions we encouraged questions and used each opportunity to obtain feedback from stakeholders. As an example, in our 2019 webinar, we encouraged participants to use the chat feature and questions we did not have time to address in the session we followed up at a later time. The webinar also facilitated access to stakeholders who we were able to contact later by phone for short interviews. Below is a list of the seminars and presentations that were conducted.

Bigelow, P., Carlan, N. (2019). Whole Body Vibration Exposures and Health Effects in Manitoba Truck Drivers . Manitoba Workers Compensation Research Meeting, Oct 2. Winnipeg, MB.

Bigelow, P., Carlan, N. (2019). Improving the Health and Safety of Truck Drivers Through Interventions to Reduce Whole Body Vibration Exposures. Feb 26. Centre for Centre of Research Expertise for the Prevention of Musculoskeletal Disorders Research Meeting.
Bigelow, P., Carlan, N., Dolhy, A. (2019) Webinar - Recommendations for Improving the Health and Safety of Truck Drivers by Addressing Whole Body Vibration, Fatigue, and Overall Health and Wellness Improving Truck Driver Health through Ergonomics and Vibration Reduction, Feb 26, 12 PM to 1 PM EST, Hosted by the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders.
Dietze, B., Eger, T., Du, B., Bigelow, P., Dickey J, (2018) Performance of Boseride and Air Suspension Seats in a Laboratory Test of Trucking Vibrations, 7th American Conference on Human Vibration, June 13 -15, 2018, Seattle, WA.
Bigelow, P., Carlan, N., Dickey, J., Du, B., Tompa, E. (2018). Exploring Approaches to Improving the Health of Truck Drivers in Manitoba by Integrating Knowledge Regarding Whole Body Vibration Exposures with Overall Driver Wellness. Canadian Association for Research on Work and Health, October, 21-23, Vancouver, BC.
Bigelow, P., Dickey, J., Du, B., Vi, P., Tompa, E., Carlan, N. (2016) Whole Body Vibration Exposure in Long Haul Drivers and the Potential for Knowledge Utilization, PREMUS2016. June 20-23, Toronto, ON.
Carlan, N., Bigelow, P. (2016) Measuring Success of Prevention: What Measures can we use to Evaluate MSD Interventions? Canadian Association for Research on Work and Health International Conference. October 16-18, Toronto, ON.
Bigelow, P., Dickey, J., Du, B., Vi, P., Tompa, E., Carlan, N. (2016) Whole Body Vibration Exposure Among Long Haul Drives and the Potential for Knowledge Utilization. PMEMUS2016: Ninth International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders, June 20-23, Toronto, ON. Tompa, E., Carlan, N., Dickey, J., Vi, P., Bigelow, P. (2016) Developing a Business Case for Musculoskeletal Disorder Prevention for the Trucking Industry. Canadian Association for Research on Work and Health International Conference. October 16-18, Toronto, ON.
Bigelow, P. Carlan, N. (2016) Identifying Risk: The First Step in a Multistage Musculoskeletal Disorder Prevention Initiative. Canadian Association for Research on Work and Health International Conference. October 16-18, Toronto, ON.
Bigelow, P. (2016) Reducing Seated Vibration in Truck Drivers to Reduce Fatigue and Back Pain. Partners in Prevention – Health and Safety Conference, April 26-27, Toronto, ON.
Carlan, N., Crizzle, A., Myers, A., Dickey, J., Tompa, E., Dolly, A., Bigelow, P. (2015) Research in Trucking. Partners in Prevention – Health and Safety Conference, April 28-29, Toronto, ON.
Bigelow, P. (2015) Reducing Seated Exposures in Truck Drivers to Reduce Fatigue and Back Pain. 14th Annual Alberta Health and Safety Conference and Trade Fair, Oct 28-30, Banff, AB
Bigelow, P., and Dolly, A. (2015) Seated Vibration in Truck Drivers and the Link to Motor Vehicle Collisions. Staff Conference Workers' Compensation Board of Manitoba, Winnipeg, MB
Bigelow, P. (2015) An Intervention to Reduce Seated Vibration in Truck Drivers. Centre of Research Expertise for the Prevention of Musculoskeletal Disorders Research Meeting, February 2015, Mississauga, ON

3.2.2 Interviews with drivers

Manitoba-based truck drivers were recruited from truck stops in Saskatchewan and Alberta and were invited to participate in semi structured interviews. These interviews were conducted in the summer of 2018 in conjunction with data collection on a truck driver health and wellness study led by Dr. Alex Crizzle of the University of Saskatchewan. A total of 12 drivers participated and the in-person interviews lasted between 5 and 20 minutes. The interviews were audio recorded and transcribed verbatim. Field notes were taken and in some instances the driver's seat was examined (to determine the make and general condition). Using NVivo, the transcripts for each session were independently analyzed.
The interviews began with asking the drivers about any body pain/discomfort they experience while driving. Demographic questions as well as questions about their truck and truck seat followed. Information about how

often their company replaces seats and how they go about making decisions about seat procurement was obtained. The interview questions are shown in the appendix (see sections 7.1 and 7.2).

3.2.3 Interviews with managers

There are key players in trucking companies that make decisions about truck seats. Managers and others having decision-making authority were interviewed regarding purchasing decisions when new trucks or seats are needed. Questions were asked to gain information about the decision-making process and how and if scientific evidence plays a role. Respondents were asked what their most pressing issues are and how health, safety and wellness is prioritized. The interview questions are contained in the appendix (see section 7.3).

3.3 Research Ethics

Ethical considerations of informed consent, anonymity, confidentiality and data security were observed for all data gathering events and for the stakeholder workshops. The University of Waterloo's Office of Research Ethics and the Western University Health Sciences Research Ethics Board provided formal ethical clearance for this study. Care was taken to ensure the confidentiality of participants. Participants were informed they had the right to skip any question or end/leave the interview or experiment at any time without penalty. They also were informed they had the right to withdraw their participation from the study. No participants asked for their data to be withdrawn. The study material is retained by the immediate study team in a secure location.

4 FINDINGS

The research findings are presented below and grouped by the phases of the investigation.

4.1 Finding from Field and Laboratory Vibration Studies

4.1.1 Field study

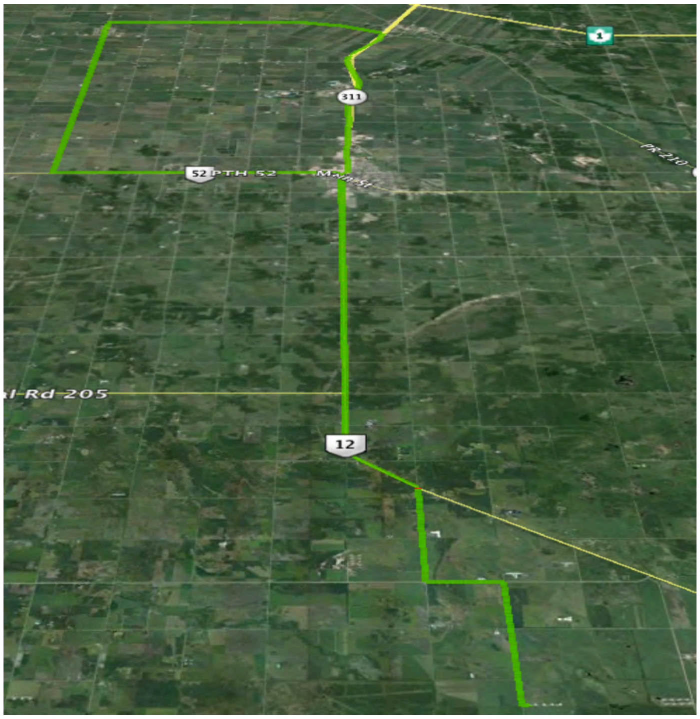
In Manitoba 425 trucking companies employ 13,668 drivers We were able to test 33 trucks and the vibration data for 24 trucks was complete and reliable. The majority of the vehicles were driven by hired drivers representing 6 different companies. and five drivers were independent operators. For the 24 trucks we were able to record whole-body vibration linked to GPS data for loaded and unloaded vehicles driving on a variety of roads in the Winnipeg area.
Table 4.1 provides a summary of the participant demographics for the field study along with seat type for the truck they were driving as wll as the drivers' perceptions of pain/discomfort (1-5 scale with 5 being the worst) by body part.

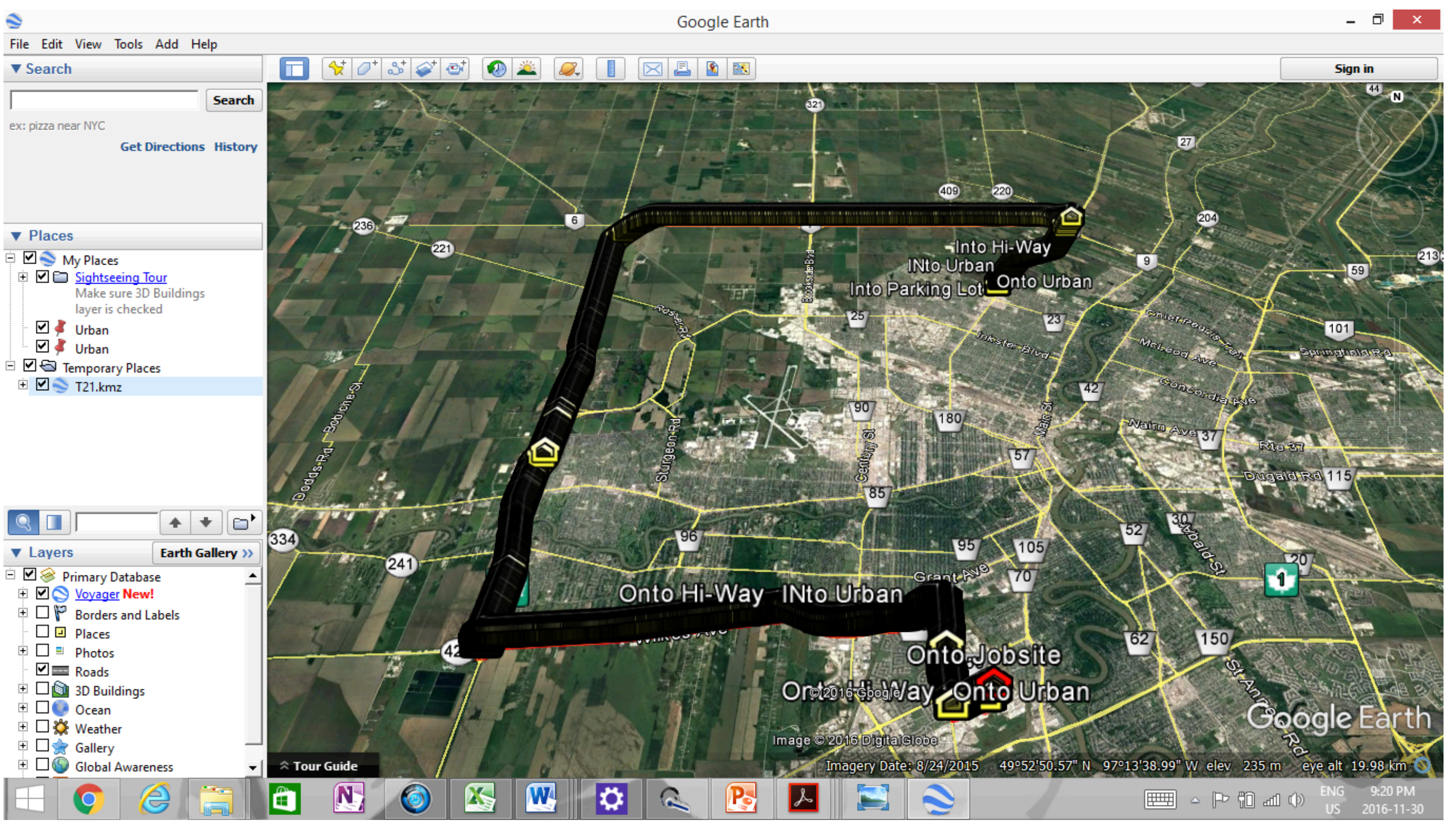
Table. 4.1 Physical complaints and information on participating truck drivers.

ID	Age	Yrs of driving	Hrs/wk	Seat type	Weight kgs	Height cms	Physical complaints
1	37	10	40	Air ride	82	180	none
2	56	30	63	unknown	86	175	Shoulder 3 Neck 3 Low back 3
3	52	23	60	Air ride	113	185	Shoulder 3 Neck 3 Low back 3
4	45	21	65	Air ride	113	180	Shoulders 5 Low back 5 thigh 5
5	43	22	63	Air ride	88	186	Neck 3 Low back3
6	45	28	63	Boseride EAVC	79	165	Neck 5 Mid back 5 low back 3
7	59	18	63	Boseride EAVC	104	180	Neck 5, head 5 shoulders 5 back5 legs 5
8	57	36	60	unknown	154	172	unknown
9	27	8	50	Air ride	93	178	Left shoulder arm and leg 5
10	69	51`	40	Air ride	113	190	Both legs 3
11	34	6	45	Air ride	100	172	none
12	45	25	na	Air ride	100	184	Low back 3
13	65	45	na	Air ride	113	188	unknown
14	56	16	45	Air ride	113	185	Shoulder 3 low back Right wrist 3
15	48	25	na	Air ride	113	190	Shoulder 4
16	58	41	na	National	106	175	Low back4
17	62	34	45	Air ride	84	178	none
18	45	25	40	Boseride EAVC	100	184	none
19	40	17	50	Legacy	na	178	none
20	28	4	40	Air rise	95	178	Neck/shoulder 3 Low back 3
21	64	44	50	National	91	172	unknown
22	40	22	30	Legacy	82	180	none
23	50	30	67	Air ride	118	168	unknown

Figure 4.1 below shows examples of plots of seat top vibration data by route in 20 second segments. Green lines indicate segments with exposures values below the ISO 2631-1 Health Guidance Caution Zone whereas yellow is above the action limit. However, given drivers spend very limited time on roads that were yellow or red, their overall time weighted average daily exposures were less than the Health Guidance Caution Zone.

Figure 4.1 Examples of a GPS and Vibration Data Visualization





Summary of qualitative data collected from drivers and employees in trucking firms

The ability to conduct a field study of the trucking industry rather than a company specific study is complicated by the organization of work. There are at least four employment relationships: drivers employed by a trucking or other firm; drivers contracted to a firm who own their own rig; independent owner operators and drivers working in partnership with an independent owner. These employment relationships are relevant because they dictate the entitlement to workers compensation benefits and reporting of injuries. They also dictate the economic benefits of purchasing expensive seats to limit vibration. If the only economic benefit is for protecting direct employees there is limited financial incentive to make an expensive investment.

Furthermore because of the non-traditional employment relationships, many trucking firms do not assume responsibility for fines attributable to unsafe vehicular conditions. It is the responsibility in many companies that the driver must ensure that the vehicle is road worthy. If the vehicle is stopped and a fine is given for a safety violation many companies require the driver to assume responsibility to pay the fine levelled because of unsafe equipment

In addition to employment relationships, control over the workplace is also different from most typical workplaces. Obviously, some of the conditions in the workplace are beyond the control of an employer. For example, the condition of the roads, the sites for deliveries and the weather all impact on driver safety and are beyond employer control. In addition, there are no nationally consistent training requirements for drivers and the workplace can be populated by untrained drivers who add hazards to the workplace.

The information and data gleaned from this study group was also limited because we were advised that vibration issues were more noticeable for in town and delivery drivers. Weight and load issues were more variable and city roads were more susceptible to winter damage and potholes.

4.1.2 Laboratory Study[3]

A library of vibration exposures from the field study were created for use in the laboratory (seats were mounted on a 6 df motion platform with a human operator) to quantify the WBV attenuation characteristics of electromagnetically active (Bose Ride) and passive suspension seats (Legacy) across varying amplitudes and a range of frequencies. Table 4.2 provides the details of the truck and seats from which the field WBV data was collected.

Table 4.2. Truck make/model, year, Trailer, Load (Kg), and seat model and model year for 25 trucks used to create vibration library (NA – information unavailable)

Truck	Make/Model	Year	Trailer	Load (Kg)	Seat Type and Date
1	Volvo	N/A	N/A	N/A	N/A
2	Volvo	N/A	N/A	N/A	N/A
3	Volvo	N/A	N/A	N/A	N/A
4	Volvo	N/A	N/A	N/A	N/A
5	Volvo	N/A	N/A	N/A	N/A
6	Volvo D12 Day Cab	N/A	N/A	N/A	Bose Ride®
7	Volvo D12 Small Bunk	2012	Flat bed trailer	9000	Man Seat - 2016
8	Freightliner Cascadia Day Cab	2016	Great dane	11000	Man Seat - 2016
9	Volvo D13	2011	Gravel trailer	54000	Man seat - 2011
10	Mack Pinnacle	2015	Super B	57000	Man seat - 2016
11	Volvo - D13	2015	Tandem turn pike 253	N/A	Man seat - 2015
12	Volvo D15 Day	2013	Step deck	N/A	Man. Seat - 2012
13	Volvo D15 Day	2013	Step deck	N/A	Man. Seat - 2013
14	Volvo D13 Day Cab	2014	Super 8	60000	Man. Seat - 2014
15	Kenworth T800	1999	Flatbed	N/A	Seats Inc. - 1999
16	Volvo D13 Day Cab	2010	Tri-axle HiBay	16000	National - 2016
17	Volvo D13 Day Cab	2010	Tri-axle HiBay	22000	National - 2016
18	Volvo D13 Day Cab	2013	Triden step deck	N/A	Man seat - 2013
19	Freightliner Cascadia	2014	Two van trailers	N/A	Bose Ride® - 2014
20	Peterbilt 379 LongNose	2012	Wilson Livestock	36000	Legacy - 2002
21	Freightliner Cascadia	2016	Wilson Livestock	45000	Man. Seat - 2016
22	Western Star 4964F	1994	Step deck	20000	National - 1996
23	Kenworth T800	2004	Wilson Livestock	45000	Legacy LoSilver - 2015
24	Kenworth T800	2004	Wilson Livestock	N/A	Legacy LoSilver - 2016
25	Peterbilt 579	2015	Dry Van - Trailer tail	18000	Std Air ride - 2015

The vibration library included information on the road types that drivers drove on in the field study conducted in the Winnipeg area. Drivers typically drove on a variety of roads classified as: highway, urban, provincial, rural and jobsite. For the modeling, two variants of exposure were calculated based on the proportion of driving

3 More detailed information regarding the laboratory study is available (Dietze, B. Comparison of Whole-body Vibration Attenuation Properties Between Active and Passive Suspension Seats (2020). Electronic Thesis and Dissertation Repository. 7277. https://ir.lib.uwo.ca/etd/7277) on the various road types. Variants of highway bias and the rural road bias represented the data well. The highway biased A(8) calculations had the majority of the theoretical exposure provided from highway exposures. The rural bias exposures had the majority of exposure time coming from rural and provincial roads. The breakdown of time spent on each rank of road for the theoretical exposure is summarized in Table 4.3 (see methods section for the rank definitions).

Twenty-five individuals participated in the laboratory study. Their height and weight were self reported and their BMIs ranged from 22 to 39 kg/m2. Participants were classified into normal, overweight, and obese categories. Group mean and standard deviation was 22.6 ± 0.52 kg/m2, 28.0 ± 1.6 kg/m2, and 32.8 ± 3.5 kg/m2 for normal, overweight, and obese groups respectively. All experimental measures were collected in a single session for each participant. The experimental sessions were approximately 45 minutes long with both seats being tested in the same session.

Table 4.3 Weighted RMS accelerations for predicted Bose Ride and Legacy seat vibration exposures, theoretical exposure (TE) time for rural and highway bias, and vibration ranking for daily vibration exposures used to calculate A(8) for two theoretical drivers (TD) with normal BMI.

		Hi-Way Bias		**Rural Bias**		**TD1**		**TD2**	
Road type	Rank	Time TE1 (Min)	Time TE2 (Min)	Time TE1 (Min)	Time TE2 (Min)	Bose	Legacy	Bose	Legacy
Highway	333	47	47	6.67	6.67	0.3423	0.3947	0.3422	0.4691
Highway	323	47	47	6.67	6.67	0.2086	0.3342	0.2112	0.3675
Highway	312	47	47	6.67	6.67	0.2057	0.3678	0.2053	0.2985
Highway	121	47	47	6.67	6.67	0.2386	0.4048	0.2255	0.4403
Highway	232	47	47	6.67	6.67	0.2808	0.4510	0.3088	0.4494
Highway	233	47	47	6.67	6.67	0.3191	0.5405	0.3321	0.4944
Urban	332	6.67	0	5	0	0.2663	0.3660	0.2774	0.3647
Urban	222	6.67	0	5	0	0.1641	0.2916	0.1721	0.2595
Urban	233	6.67	20	5	15	0.3423	0.4454	0.2903	0.5261
Urban	212	6.67	20	5	15	0.1682	0.2950	0.1795	0.3100
Urban	333	6.67	0	5	0	0.2769	0.4436	0.2706	0.5758
Urban	323	6.67	0	5	0	0.1727	0.3887	N/A	N/A
Rural	232	3.33	5	15	22.5	0.2606	0.3146	0.2482	0.3477
Rural	333	3.33	0	15	0	0.4658	0.5459	0.5073	0.7140
Rural	323	3.33	5	15	22.5	0.2201	0.3241	0.1898	0.3623
Rural	212	3.33	5	15	22.5	0.1352	0.2447	0.1409	0.2629
Rural	222	3.33	5	15	22.5	0.2402	0.3521	0.2479	0.3424
Rural	111	3.33	0	15	0	0.1682	0.1863	0.1588	0.1858
Provincial	233	6.67	0	35	0	0.2767	0.5151	0.2751	0.5270
Provincial	333	6.67	0	35	0	0.3660	0.4510	N/A	N/A
Provincial	211	6.67	0	35	0	0.2289	0.3958	N/A	N/A
Provincial	312	6.67	13.33	35	70	0.3039	0.5097	0.3024	0.5266
Provincial	212	6.67	13.33	35	70	0.2269	0.3811	0.2176	0.4667
Provincial	323	6.67	13.33	35	70	0.2891	0.4337	0.2671	0.4321
Jobsite	323	1.33	0	3.33	0	0.0733	0.0995	0.0704	0.0885
Jobsite	223	1.33	0	3.33	0	0.0420	0.0570	0.0306	0.0485
Jobsite	222	1.33	2.67	3.33	6.67	0.0305	0.0422	0.0319	0.0422
Jobsite	332	1.33	2.67	3.33	6.67	0.1136	0.1209	0.1160	0.1169
Jobsite	333	1.33	2.67	3.33	6.67	0.2802	0.2923	0.2636	0.2797
Jobsite	322	1.33	0	3.33	0	0.0536	0.0659	0.0531	0.0574
Off		90	90	90	90	0.0000	0.0000	0.0000	0.0000
Total		480	480	480	480				

Predicted A(8) frequency weighted daily WBV exposure values at the participant/seat interface for field exposures with highway bias and rural/provincial road bias are presented in Figure 4.2 and Figure 4.3. No theoretical exposure for any group with a highway or rural bias exceeded the ISO 2631-1 Health Guidance

Caution Zone action limit. The Bose Ride seat had lower predicted daily vibration exposure than the Legacy seat across all comparisons.

Figure 4.2 Predicted daily vibration exposure normalized to 8 hours with rural/provincial road bias for truck operators with different BMIs for both the Bose Ride (blue) and Legacy(red) seats. Circles represent normal BMI, triangles obese BMI and squares overweight BMI. Blue horizontal lines represent the upper and lower limits of the EU directive action limits and the red lines represent the upper and lower limits of the ISO 2631-1 Health Guidance Caution Zone.

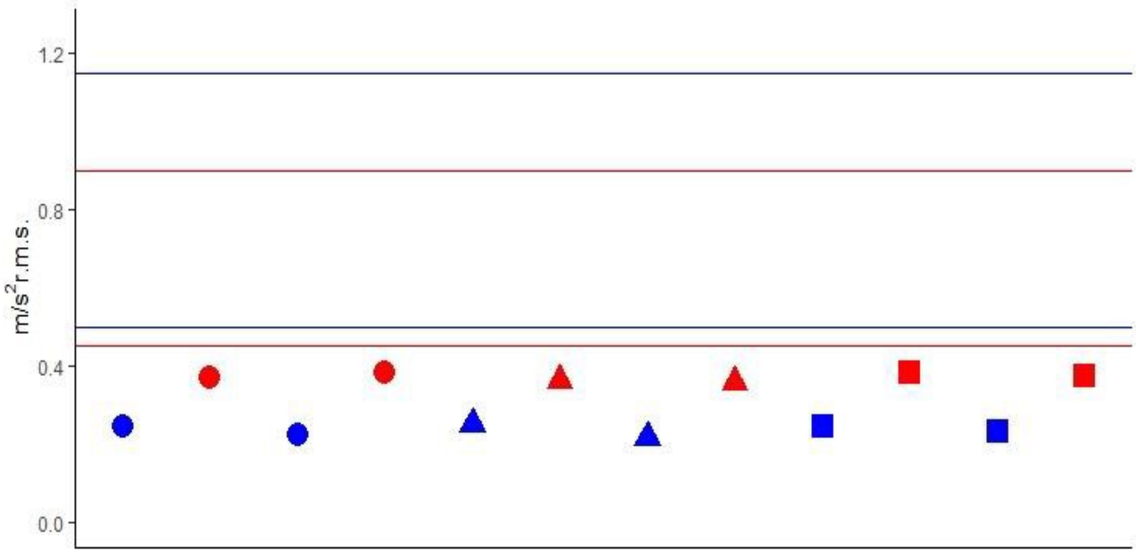
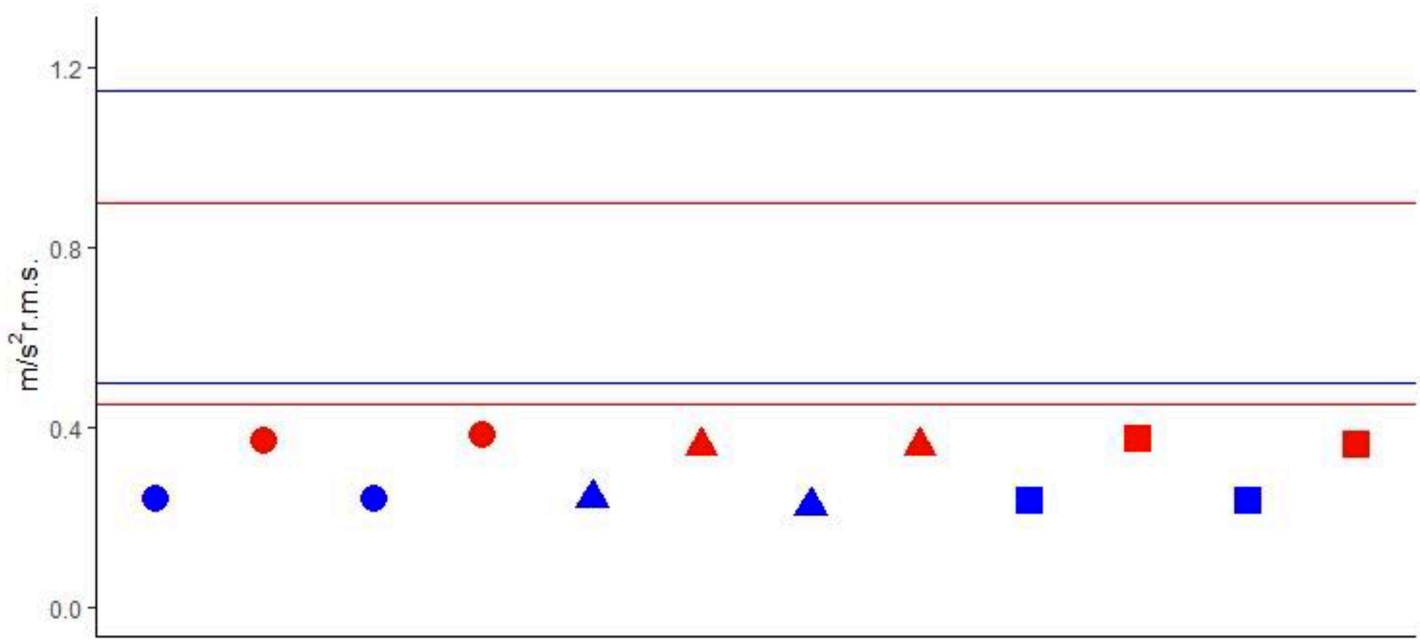


Figure 4.3 Predicted daily vibration exposure normalized to 8 hours with highway bias for truck operators with different BMIs for both the Bose Ride (blue) and Legacy (red) seats. Circles represent normal BMI, triangles obese BMI and squares overweight BMI. Blue horizontal lines represent the upper and lower limits of the EU directive action limits and the red lines represent the upper and lower limits of the ISO 2631-1 Health Guidance Caution Zone.



Attenuation effectiveness of the active suspension and passive suspension seating systems

An crucial component of the laboratory study was to provide evidence regarding the efficacy of commercially available active and passive suspension seats as interventions for reducing the health risks caused by WBV for long haul truck drivers on typical roads in Manitoba.
Findings for the active suspension seat (Boseride) and typical passive suspension seat (Legacy) are provided below grouped by the axis of measurement.

X and Y axis
There was no differences in performance of x and y-axis attenuation between the two seats in the field exposures (figures 4.2 and 4.3) and the random x-axis exposures (figure 4.5). The Boseride seat did outperform the legacy silver seat in the random y-axis exposures (figure 4.6). The SEAT values of the Boseride for random y-axis vibration were roughly equal to 1 meaning that even though it did outperform the legacy seat; the Boseride seat attenuated very little vibration at best. This coupled with not observing the improved attenuation of y-axis vibration in field exposures leaves one to be hesitant to recommend the Boseride seat as a solution for environments with excessive x and/or y-axis vibration exposure.

Figure 4.2. SEAT values for field exposures on x axis. Lower is better

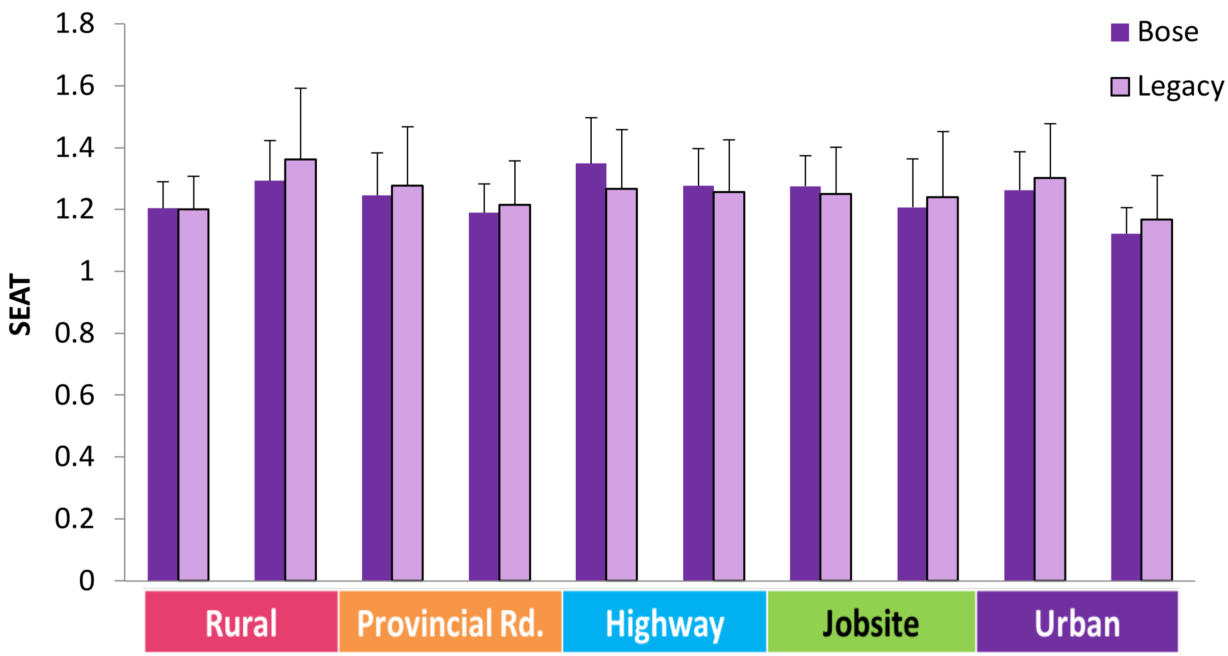


Figure 4.3 SEAT values for field exposures on y axis. Lower is better.

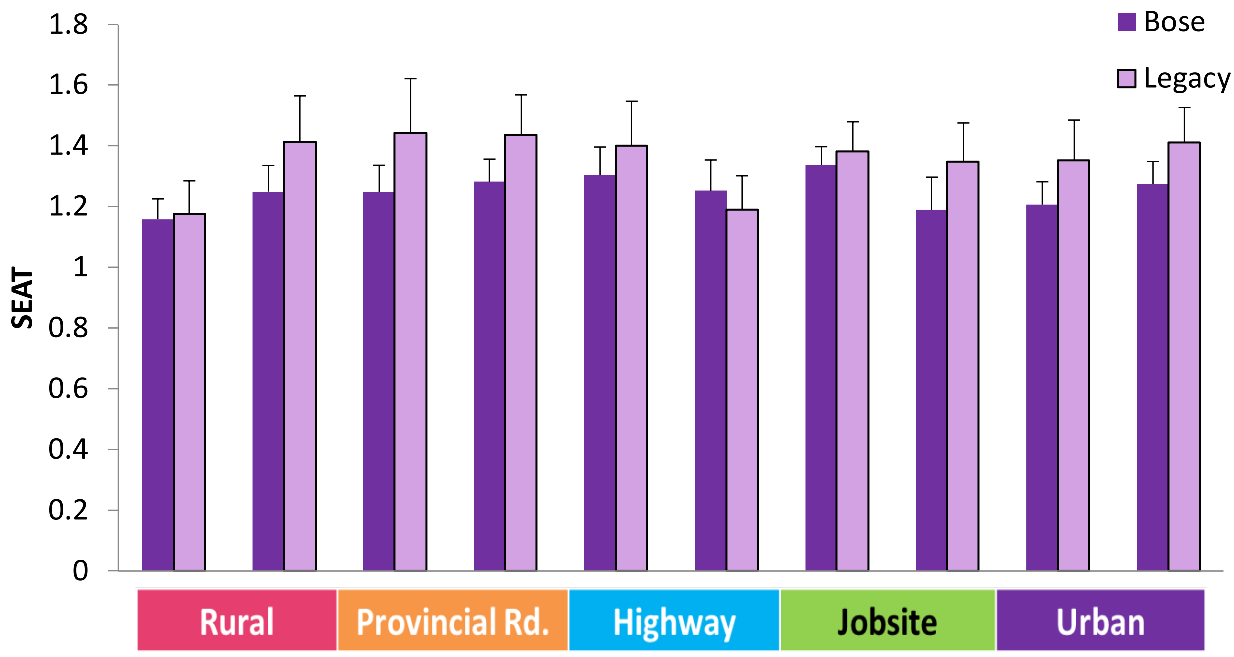


Figure 4.4 SEAT values for field exposures on Z axis. Lower is better.

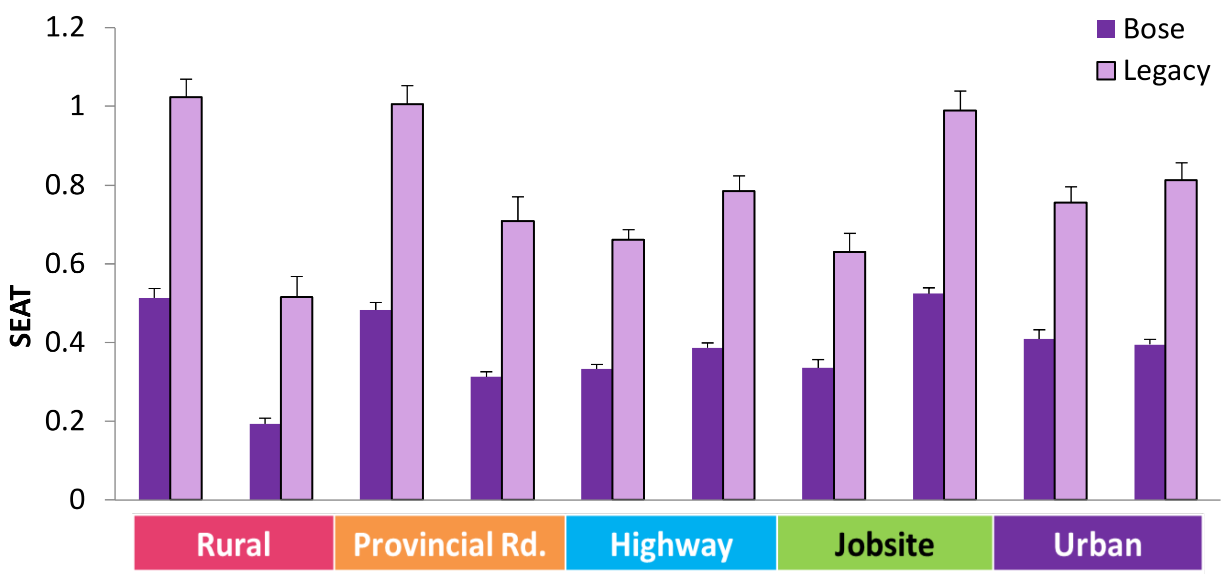


Figure 4.5 SEAT values for random exposures on X axis. Lower is better.

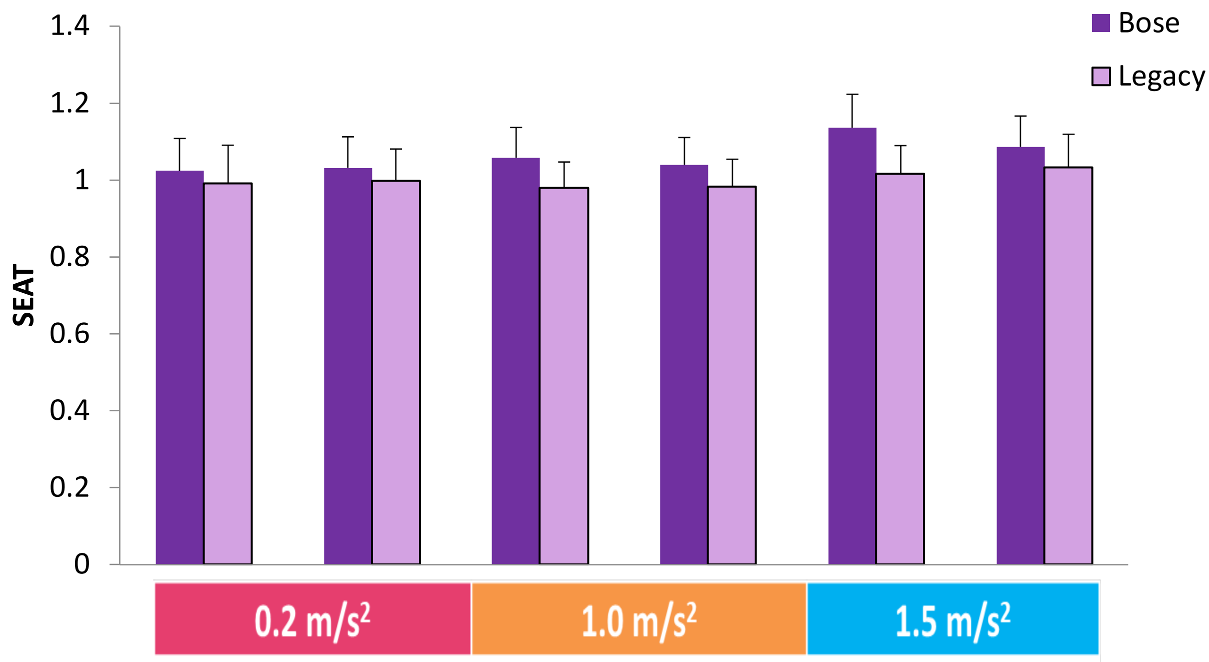
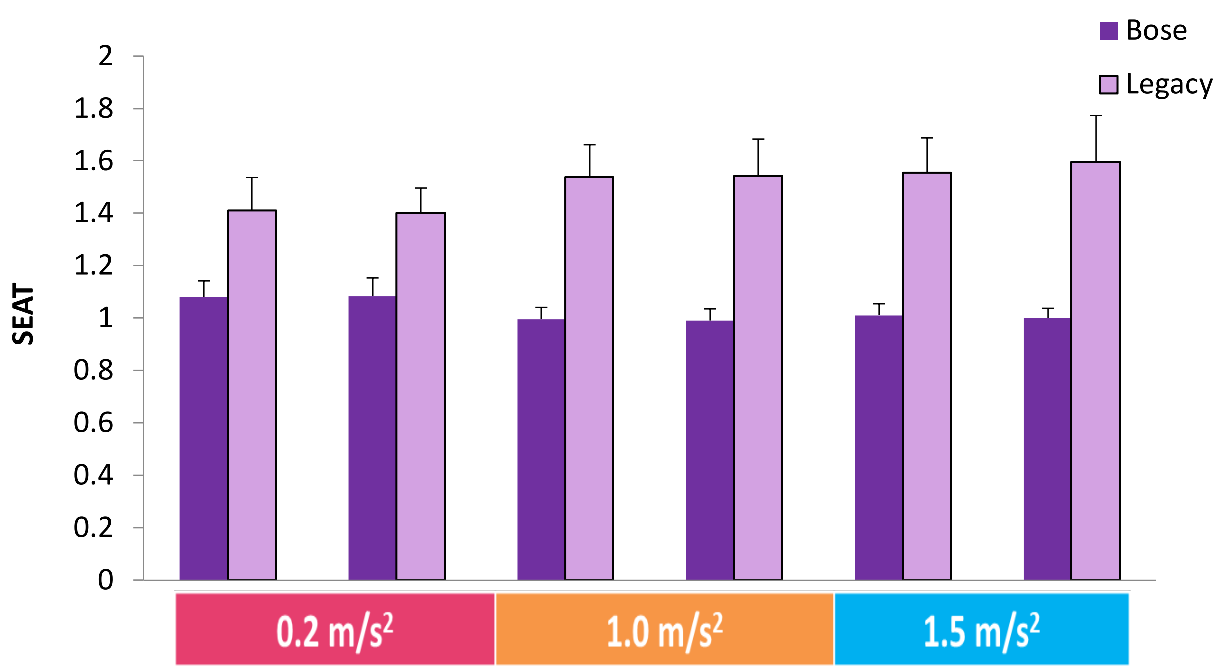


Figure 4.6 SEAT values for random exposures on Y axis. Lower is better.



Z axis

The Boseride seat outperformed the legacy silver for z-axis vibration attenuation in every test (figure 4.7). As the acceleration increases the gap between attenuation performance of the seats closes. However, the performance of the legacy silver never surpassed the Boseride in Z-axis vibration attenuation.
If the vibration profile of the work environment is predominantly z-axis based the Boseride will be more effective in reducing whole body vibration injury.

Figure 4.7 Total Vibration (A(8)) by Seat for a Typical Road Segment

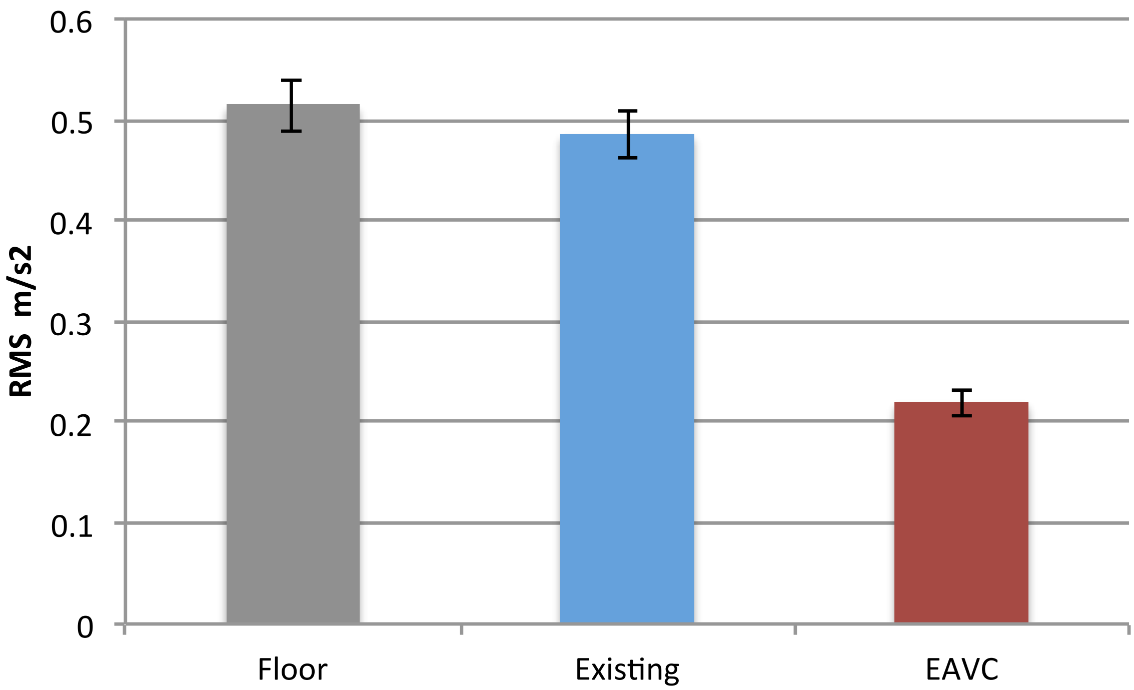
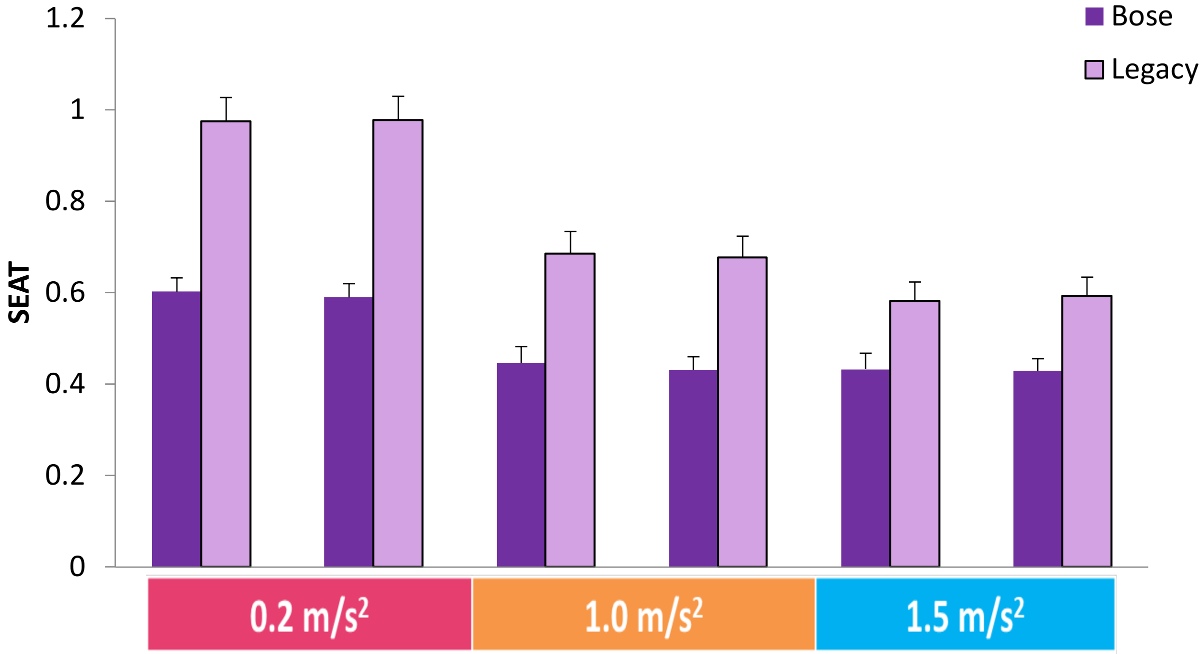


Figure 4.8 SEAT values for random exposures on Z axis. Lower is better.



4.1.3 Interviews with Drivers in the Field Study

Drivers are characteristically individualistic and not prone to participate in collective studies or activities. They did not identify exposure to vibration, or any other prolonged exposure, as a safety issue. The respondents in this study had an average age of 39 and had been driving for an average of 19 years. The drivers began driving early in their working lives and had continued with the vocation.

Vibration was not an issue for the drivers in the field study. Also of interest was the fact that only 2 drivers had a workers compensation claim related to driving. In both of those case there were specific accidents and not claims for MSDs. These reports are consistent with WCB data which indicates that drivers' injuries usually result from jumping down from the truck or trailer base.

Long term drivers who owned their own vehicles were also noteworthy because of their pride in their vehicles including the seats. Not only were they conscious of comfort but also aesthetics. For example, one driver had installed hardwood flooring in his cab to enhance its beauty. In contrast the decisions of the recent immigrant drivers, who form a growing component of the driver workforce, cost was key decision factor. These drivers were trying to establish their lives in Canada and costs were a critical issue. Vibration did not influence their decisions.

Vibration did influence seat choice for drivers with previous back injuries. These drivers found that limiting vibration exposure allowed them to continue working with limited discomfort.

4.2 Interviews with Drivers and Managers

4.2.1 Truck Driver Interviews

A total of 41 drivers were approached and invited to participate in interviews at truck stops in Saskatchewan and Alberta. Most drivers initially contacted were not based in Manitoba so were not eligible. Only one driver from Manitoba refused to participate. All 12 of the participants were long-haul drivers and the majority (n=7) reported working for carriers with the others owning their own truck (either owner-operators or contracted to a carrier). Most drivers were over 40 years of age and the oldest reported being 65.

Most reported having been a truck driver for over 10 years. One of the participants was a woman. Most reported they were full-time drivers and typically drove long-haul routes across the prairies and into BC. A few participants reported that they sometimes had routes that took them into Ontario and the US.
The most common reported makes of tractors were Volvo and Kenworth although a number drove Freightliners and Peterbilts. The majority reported their trucks were less than 4 years old. Few reported knowing the make or age of the trailer. All reported that their cab and seat had air suspension systems. Most reported that they did not know or remember the make of the seat but that it came with the truck when purchased (the most commonly reported seats were Bostrom and Sears). A few of the drivers mentioned that they would replace the seats after 3 or 4 years however a few drivers also reported that their companies keep their tractors for only 3 or 4 years. Six of the participants reported some pain or discomfort from driving. Of the 16 areas of the body on the body pain/discomfort map the six who reported discomfort all circled the back (lower, mid and/or upper back). The mean level of pain/discomfort for those reporting pain/discomfort in the back was 2.1 on a 1 to 5 scale with 5 being the highest level. One of these individuals also reported pain/discomfort in the shoulder and arms. None reported lost time due to a driving related injury or condition.

Themes from the interviews
Pain is part of the job. The majority of drivers felt that their seats were comfortable and were not worried about back pain. One driver felt that back pain was part of the job: "Hey, I do a lot of sitting and I'm stiff and a little sore at the end of the day, but that's the job and that's the way it is". Another driver mentioned he was more worried about getting a back injury from lifting as opposed to any concern about his seat.

New trucks and seats are comfortable. Drivers were often very proud of their trucks and one driver, with a new Peterbilt was so proud that he brought out his phone and showed photos. For many of the drivers, especially those with the new tractors (2017-2019) they felt they had very high-end seats that were comfortable. When asked about vibration they had no concerns. Drivers generally felt that vibration is not a concern. "Things are much better now" one driver mentioned referring both to the trucks and the roads. A few drivers mentioned that some seats are more comfortable than others but did not comment that any one particular seat was better from a vibration perspective. Most felt that air suspension systems in their trucks and seats made the ride much more comfortable.

Vibration not a major issue. Four of the drivers felt that fatigue was a problem but did not mention a link to vibration exposure. When probed about vibration and fatigue a few drivers thought it sounded possible they could be related although they did not mention any personal experiences. None of the drivers had driven a truck with the Bose Ride (active suspension) seat. Two drivers knew about the Bose Ride and one felt that big carriers who wanted to keep their drivers had those seats in their trucks. One driver had heard that the Bose Ride was helpful for drivers if they had back problems.

Cost a major concern in decision to purchase active seats. As most participants were happy with their existing seat, they were reluctant to consider replacing their seat because they felt that a vibration reducing seat would be expensive. Owner operators were vocal in expressing the competitiveness of the trucking sector and so folks could not afford more expensive seats. The company drivers felt that they had some say in purchasing new seats for the trucks they drive although if the cost differential was too high it would be unlikely to be approved. One driver mentioned that a new seat would need to have little maintenance and have the adjustments and features that his current seat has.

Comparison of findings from interviews with findings from an intercept study of Canadian long-haul truck drivers
Participants who were interviewed also were eligible for participation in a long-haul truck driver health and wellness study led by A. Crizzle of the University of Saskatchewan (U of S) that was being conducted concurrently. Given the similarities in recruitment for the two studies, a comparison of findings may be informative. The U of S study included survey questions relevant to WBV and its effects.

There were 238 long-haul drivers who participated in the U of S study and their average age was 52.5, 96% were men, and average reported number of hours worked per week was 57.1 (A. Crizzle, personal communication). Twenty nine percent of the respondents reported having lower back pain in the last three months that lasted a whole day or more. Drivers were asked how many days in the last 7 days they felt fatigued during their work period and 45.5 percent reported at least one day. Of those reporting fatigue, the mean number of days feeling fatigued for part of their work shift was 1.92.

4.2.2 Additional Interviews with other workplace parties

Cost and comfort were major considerations for managers who had the purchasing responsibility. Vibration exposure was not a major consideration. Ownership of trucks was a key factor in equipping and maintaining trucks. Large firms often leased their equipment and those agreements dictated a maintenance schedule. One mechanic advised us that in addition to normally scheduled tasks like brakes he also evaluated the status of the seats. Because he had the authority to make purchases, he acquired a number of seats which were off colour. He would use these surplus eats to make replace worn seats on a regular basis.

4.3 Document Analysis

4.3.1 Peer reviewed literature

The research team completed a review of the peer reviewed literature and identified the key literature in areas, specific to truck drivers, of WBV exposure, WBV health impacts, and the interaction of WBV and posture on health outcomes.

Key Peer Review Literature Relevant to WBV in Truck Drivers

Theme	Author/Yr	Article	Study Type	Evidence/Findings	Main Conclusions
WBV Exposure	Cann, Salmoni, Eger - Ergonomics, 2004	Predictors of whole-body vibration exposure experienced by highway transport truck operators	Field study on WBV exposures compared to 1997 International Standards Organization (ISO) 2631-1	Statistically significant relationships were observed between WBV exposures and road conditions and truck type Overall mean frequency weighted RMS acceleration 0.44 m/s2 range of 0.04 –1.08 m/s2. Dominant axis for operator WBV exposure was the z-axis.	key predictors of WBV exposure levels were road condition and truck type Most WBV exposures below health caution zone level
	Ryou, Johnson Proc Human Factors Ergo 2018	Whole-Body Vibration Exposures Among Solid Waste Collecting Truck Operators	WBV and seat effective amplitude transmissibility (SEAT) values for 12 trucks	Most A(8) and all VDV(8) Z-axis (predominant) exposures above action limits -	SEAT values from 0.73 (about 27% attenuation) to 1.81 (about 81% amplification) -
	Nitti, De Santis - Industrial Health, 2010	Assessment and Prediction of Whole-body Vibration Exposure in Transport Truck Drivers	WBV measures (24 test runs) and statistical modeling	Regression models for association of truck parameters (load, suspension systems, road roughness) with vertical axis WBV -	Order of importance of predictors = Road roughness > Speed > Susp. Fitting > Load Increase speed and no-load increase WBV - Discussion of advances in suspension technologies

WBV Exposure – Health				-	-
	Teschke, Nicol, Davies, Ju – Report to Workers' Compensation Board of BC 1999, doi: http://dx.doi.org/10.14288/1.0048193	Whole Body Vibration and Back Disorders Among Motor Vehicle Drivers and Heavy Equipment Operators: Review of the Scientific Evidence	Review and analysis	Hill's criteria for causation applied to 25 studies of drivers - Confounders age, working posture, lifting, previous back pain, smoking, stress, job satisfaction, body type	Support a causal link between back disorders and both driving occupations and WBV. Numerous back disorders including lumbago, sciatica, generalized back pain, and intervertebral disc herniation and degeneration. Elevated risks consistently observed after five years of exposure
	Koley., Sharma, & Kaur, Anthropologist, 2010	Effects of occupational exposure to whole-body vibration in tractor drivers with low back pain in punjab.	Cross sectional	169 tractor drivers – 17 % report back pain increase of pain scores with the increased exposure to whole-body vibration	Pain exacerbated with exposure to WBV
	McBride, Paulin, Herbison, Waite, & Bagheri Arch Occup Env Health, 2014	Low back and neck pain in locomotive engineers exposed to whole-body vibration	Random sampling of employee database for controls; vibration measures in exposed workers	Median vibration exposure in the z-axis: 0.62m/s^2 for exposed group (n=340); signif increase lost time prevalence (OR 1.74)	Numerous finding mixed results
	Knox, Orchowski, Scher, Owens, Burks., & Belmont, Spone 2014	Occupational driving as a risk factor for low back pain in active-duty military service members	Retrospective cohort	Query performed using the US Defense Medical Epidemiology Database for the International Classification of Diseases, Ninth Revision,	The overall incidence rate of low back pain in our military vehicle operator population was 54.2 per 1,000 person-years. Service members with other occupations had an overall incidence rate of low back pain of 48.3 per 1,000 person-years. Using this control group as the referent category, military vehicle operators had a significantly increased adjusted IRR of 1.15 (95% confidence interval [CI] 1.13–1.17).
	Eger, Contratto, Dickey,. J Low Freq Noise, Vibration, Active Control 2011	Influence of driving speed, terrain, seat performance and ride control on predicted health risk based on ISO 2631-1 and EU Directive 2002/44/EC.	WBV measures of load-haul-dump vehicles and modeling of health risk	Vehicle load, lower speed, smoother roads reduced WBV Installed seats amplified WBV (SEAT values above 1.0 or 100%) -	Seats that are optimized for vibration reduction (tuned for the dominant frequencies in the 3.3 Hz range) significantly reduced operator exposures and predicted health risk Supports other studies (Paddan & Griffin, 2002; Blood et al., 2010) that selection of appropriate seat

					can reduce WBV exposure and risk to health
	Kim, Zigman, Dennerlein, Johnson. Proced Hum Fact Erg 2016	Cross-sectional Analysis of Whole-Body Vibration Exposures and Health Status among Long-haul Truck Drivers	Data from Randomized Control Trial for cross-sectional analysis; 96 long-haul drivers	Median and 25th percentile VDV(8) exposures above ISO and EU action limits (9.1 $m/s^{1.75}$) (predominant axis was Z for all exposures); A(8) Z axis less than action limits A(8) vector sum > action limits ($0.5m/sec^2$) -	VDV(8) above action limits show high impulsive (shock) exposures that likely increase intervertebral disc damage; Low back pain (LBP) prevalence was 72.5% (higher than non WBV exposed occupations at 30%) SF-12 physical health scores for drivers lower than the general US population Vector sum A(8) values significantly correlated to lower physical health scores and LBP Current daily action limit values ($0.5\ m/\ sec^2$)may be too high -
	Bovenzi et al., 2009.	Metrics of whole-body vibration and exposure–response relationship for low back pain in professional drivers: a prospective cohort study	Prospective cohort n=537 drivers (garbage truck, semi-tractors, fork lifts, cranes, loaders, etc.)	Prevalence of LBP related to WBV intensity Period prevalence LBP=64% Duration of exposure in total driving hours better predictor of LBP than full-time driving years -	Evidence for cause/effect of WBV exposure and LBP WBV measured according to the fourth power averaging method better relationship with LBP (VDV better characterizes vibration containing peaks or shocks) -
	Du., Bigelow, Wells, Davies, Hall, Johnson, Ergonomics 2018	The impact of different seats and whole-body vibration exposures on truck driver vigilance and discomfort.			Strengthens evidence of relationship of WBV and vigilance

Posture	Shibata, Maeda Ishimatsu. 4th Int Confer Whole-Body Vibration Injuries. Montreal, June 2-4, 2009.	Determination of seat back angle on biodynamic response: Study for the prevention of low back pain	Experiment with 12 participants WBV at 0.8 m/sec^2 seated at 90, 100 and 120 degrees	Significant differences in total absorbed power at all seat angles	- "VPA represents vibration power transmitted and then absorbed to the body, which has been believed to relate with damage potential associated with low back pain. This is based on the idea that energy absorbed by the body causes strain and heat internal structures of the body. In this respect, our results suggest that the optimum seatback angle range, from the viewpoint of health risk on low back pain, exists between 100° and 120°."

4.3.2 Information from Research Organizations, Health and Safety Associations, Transport Agencies

Website and other key resources relevant to truck driving and vibration health effects were identified and the findings are presented below.

Key Grey Literature and Resources

Theme	Author/Yr	Title and Website	Main Content Relevant to WBV and LBP in Trucking
General WBV and Health	Canadian Centre for Occupational Health and Safety (CCOHS) Document confirmed current on January 3, 2018	OH Answers Fact Sheets. Vibration – Introduction https://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_intro.html	- Why measure or evaluate vibration exposure? - What is vibration? - What is resonance? - How does the vibration exposure occur?
		OH Answers Fact Sheets. Vibration – Health Effects https://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_effects.html	- What are the health effects of whole-body vibration? - How much vibration exposure has to accumulate before people are affected? - Are there laws regarding vibration exposure at work?
	Document last updated on February 1, 2017	OH Answers Fact Sheets. Vibration - Measurement, Control and Standards https://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_measure.html	- How can you measure vibration? - Are there methods for controlling exposure to vibration? - Are there any Canadian regulations or guidelines for vibration exposure? - What are the standards or guidelines for exposure to whole-body vibration? "The American Conference of Governmental Industrial Hygienists (ACGIH) has developed

			Threshold Limit Values (TLVs) for whole-body vibration exposure. The 2016 edition refers to the ISO Standard 2631-1 "Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration" (published in1997, and confirmed current in 2014). The Standard focuses on the possible effects of vibration on health, comfort and perception, and on the incidence of motion sickness. They caution that vibration is often complex, contains many frequencies, occurs in several directions, and changes over time. The ACGIH TLVs use a "curve" which compares ISO 2631 Health Guidance Caution Zones, the weighted acceleration, and the exposure time, as well as a series of calculations to assist users. Use of the ACGIH and/or ISO guidelines directly is recommended. Also, it is important to remember that people vary in their susceptibility to effects of exposure to vibration so the "exposure limits" should be considered as guides in controlling exposure: they should not be considered as an upper "safe" limit of exposure or a boundary between safe and harmful levels"
Vibration Health Effects and Controls			-
	Centre for Research in Occupational Safety and Health (CROSH) Webinar, 2017	Whole-Body Vibration Exposure in the Workplace: Characteristics, Health Risks, Measurement and Control Strategies http://crosh.ca/wp-content/uploads/2018/01/CROSH-WBV-Webinar-2017-Part-1.compressed-2.pdf	- PowerPoint presentation by Dr. Tammy Eger and Wesley Killen from the Centre for Research on Occupational Safety and Health. Describes the characteristic, health risks, measurement and control strategies for whole-body vibration exposures in the workplace. Relevant industries include construction, forestry, mining, transportation, manufacturing, and agriculture.
	Centre for Research Expertise for the Prevention of MSD	Vibration Workshop (2014): Controls for Whole-Body Vibration & Hand-Arm Vibration, Ron House and Tammy Eger https://www.youtube.com/watch?v=f2q3rc87HlQ	- A conference presentation by Drs. Tammy Eger and Ron House on how to control for whole body vibration and hand-arm vibration. (video duration 32:54); 2nd half is WBV and design of seats for the vibration characteristics of the vehicle.
		Whole Body Vibration: What can we do to reduce this know health risk? Jim Dickey https://www.youtube.com/watch?v=RffQV6TqwXs&feature=youtu.be full presentation and Q&A at: https://youtu.be/aaKo73mPG7A?t=2355	- WBV is a significant health risk for four to seven per cent of the workforce, primarily operators of heavy mobile vehicles. Negative health outcomes are associated with excessive vibration exposure, including lower-back pain, spinal degeneration, gastro-intestinal tract problems, sleep problems, headaches, neck problems, autonomic nervous system dysfunction, hearing loss, and nausea. In this plenary, Dr. Jim Dickey describes two approaches that have been successfully used to evaluate seating in heavy mobile machinery. He also shares why optimized seating should be considered for some workplaces.
Seated Posture and Driving	Canadian Centre for Occupational Health and	OH Answers Fact Sheets. Driving and Ergonomics https://www.ccohs.ca/oshanswers/ergonomics/driving.html	- Can driving cause discomfort or pain? - What occupations are at risk? - What causes these aches and pains? - In general what do I need to know to improve driving comfort?

Ergonomics	Safety (CCOHS) Date modified: 2019-07-19		
	SAFE Work Manitoba Bltn. 252 Last Reviewed/Revised: September 2014 SAFE Work Manitoba Dec 2006	Ergonomics -Occupational Driving / Operating Risks for Musculoskeletal Injury https://www.safemanitoba.com/Page Related Documents/resources/Bulletin 252 - Ergonomics - Occupational Driving and Operating Risks for MSIs.pdf Guideline for the Prevention of Musculoskeletal Injuries https://www.safemanitoba.com/Page%20Related%20Documents/uploads/guidelines/musculoskeletal.pdf	- Description, graphics, and control recommendations for: Sustained or awkward postures Vibration Unsafe egress (exit) from cab Lack of appropriate warmup prior to exertion - Reference to legal requirements: Safe Work Procedures: Manitoba Regulation 217/2006 Part 2.1 Musculoskeletal Injuries: Manitoba Regulation 217/2006 Part 8 Additional workplace safety and health information available at: www.safemanitoba.com Guidance for MSD awareness and prevention
	WorkSafe BC 2015	Ergonomics for Truckers (video) https://youtu.be/ZHO_EThsKps	- Description of problems - Seat and cab adjustments - Posture - Exiting the cab – 3-point contact - Breaks
	WorkSafe Alberta 2010	Best Practices –Vibration at the Work Site https://ohs-pubstore.labour.alberta.ca/download/sample/129	- Practical guidance for recognition, evaluation and control
	Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD)	Transportation fact sheets: General trucking https://uwaterloo.ca/centre-of-research-expertise-for-the-prevention-of-musculoskeletal-disorders/resources/fact-sheets-and-handouts/transportation-fact-sheets-general-trucking Whole-body vibration: Overview of standards used to determine health risks https://uwaterloo.ca/centre-of-research-expertise-for-the-prevention-of-musculoskeletal-disorders/resources/position-papers/whole-body-vibration-overview-standards-used-determine Factors affecting operator exposure to whole-body vibration https://uwaterloo.ca/centre-of-research-expertise-for-the-prevention-of-musculoskeletal-disorders/resources/position-	- Things to consider when purchasing a truck - Ergonomic task analysis: Truck driving - Other tips sheets addressing specific MSD risk factors in trucking - - Position paper by Wesley Killen and Tammy Eger - Descriptions of ISO 2631-1 which uses the Health Guidance Caution Zone to assess general health risks based on a worker's daily exposure to WBV using A(8) or VDVtotal and ISO 2631-5 which uses stress values (MPa) and risk factor (R factor) values to suggest the risk of adverse health effects for the lumbar spine - Routine monitoring of WBV is recommended - Position paper by Wesley Killen and Tammy Eger

		papers/factors-affecting-operator-exposure-whole-body-vibration	- Key resource on truck vibration, health effects, and measures to reduce exposures grouped by vehicle factors, environmental factors, and operator factors. - Recommend that "The first line of prevention is purchasers consulting with manufacturers to select equipment with the lowest vibration emission values based on proper seat installation and suspension systems"
	Occupational Health Clinics for Ontario workers Inc	Ergonomics and Driving https://www.ohcow.on.ca/edit/files/general_handouts/Ergonomics%20and%20Driving.pdf	- Provides various behavior safety tips to combat hazards of frequent driving. Relevant for truck drivers, ambulance drivers, heavy equipment operators, taxi and limousine drivers, bus drivers, forklift operators. (5 pages pdf)

4.4 Discussion

In Phase 1 of the study the focus was developing the evidence base regarding WBV exposure in trucking and health effects as well as approaches for reducing risk. Although many drivers in the study completed musculoskeletal disorder symptom surveys the sample size was not sufficient to examine the relationship between WBV exposure and the prevalence of symptoms. If we had a larger sample size we may have been able to detect a dose-response relationship between WBV and driving-related low back pain that has been show in other investigations. However, in addition to a small sample size none of the drivers in the field study were exposed to vibration levels that exceeded the ISO Standard 2631-1 Health Guidance Caution Zones. Although having exposures averaging less than the Health Guidance Caution Zones does not guarantee no adverse effects it does indicate exposures were relatively low which makes it more challenging in epidemiological studies to detect significant associations.
The visual displays of WBV levels by road segments did provide evidence indicating which roads were roughest and provided the most contribution to overall vibration doses for drivers. This information, when provided to drivers, piqued their interest and supported anecdotal information from drivers who felt that urban roads around the city were a problem for vibration. Of course an approach to reduce vibration exposures when travelling on these road would be to reduce speed, however drivers did express concern about the added time if they were to slow down.
The laboratory study added to the evidence base with respect to the attenuation characteristics of active suspension verses passive suspension seats. SEAT values were much lower in the Z-axis for the Bose Ride seat on all roads and given the importance of Z-axis vibration in relation to vibration injury this is significant. This finding is similar to other studies of electromagnetically active suspension seats and shows they would reduce WBV exposures in Manitoba truck drivers if they were widely implemented. The document analysis provided for a review of the existing literature and informed the develop of presentations, seminars, and outreach. Some key points from the review are:

- Strong epidemiological evidence linking WBV and low back pain (LBP)
- Dose-response relationship is seen between WBV and driving-related LBP
- Healthy professional drivers with regular daily vibration exposure are at risk of developing low back symptoms over a two-year follow-up period
- Systematic review: chronic LBP is associated with sleep disturbances
- Meta-analysis: 58.7% prevalence of sleep disorders for people with non-specific LBP
- Decreased wakefulness in drivers – EEG studies
- Increased reaction times and vigilance lapses in drivers
- Conflicted results with self-reported alertness after acute exposures to WBV
- Fatigue a major problem in truck drivers - 7% have fallen asleep at the wheel; 25% have done so in the past year; 56% are tired at least some of the time while driving; 32% have driven with their eyes closed

- Implementation of active suspension seats reduces WBV exposures, reduces low back pain/ discomfort, and improves vigilance
- New technology (wearable sensors, smart phone vibration apps) for WBV assessment in drivers available and may encourage measurement and management of exposure

The focus of Phase 2 of the investigation was on transferring and translating knowledge on WBV and understanding the facilitators and barriers in using WBV knowledge to reduce exposures. The team participated in over 15 formal sessions where evidence derived from Phase 1 of the study was presented to stakeholders. Many of these sessions were at academic or technical conference but a number were within conferences/meetings that were attended by drivers and trucking company employees.

Formal interviews with drivers and managers in trucking firms were interesting but findings indicated that WBV is not on the radar for most drivers or companies. As we needed to include drivers who used active suspension seats, one of the trucking firms we collaborated with provided Bose Ride seats to a good percentage of their drivers. Drivers in this company were aware of the benefits of vibration reducing technology from a personal point of view (less fatigue etc.) and the head of OHS saw the benefits in terms of driver retention and driver satisfaction. Drivers and managers with other companies who have not adopted the active suspension seats reported that vibration was not an issue and for the most part seemed to be at the precontemplation stage in the Transtheoretical Model of behaviour change. In our interviews with drivers at truck stops which is a sample that represents more closely long haul truck drivers based in Manitoba, there was almost no knowledge of the existence of vibration cancelling seating systems and no concerns over the health effects of vibration. In many of the interviews cost of such new seating systems was an issue and there was often mention of precarious financial situation that small trucking firms and owner operators face. Structural issues in the organization of work were mentioned by some drivers and managers in trucking companies.

5 Recommendations

Further WBV exposure and health studies in truck drivers are needed to build the evidence base. Additionally, larger intervention studies looking at the effectiveness of electromagnetically active seating and driver health are important especially if they included a cost-benefit analysis. More research is needed in the area of vigilance and WBV exposures in truck drivers as it had been suggested that exposures below the Health Guidance Caution Zone may decrease vigilance and increase crash risk. Most drivers and managers in trucking firms appear to not be concerned about WBV exposures so efforts should be taken to highlight the health risks and also the benefits of reducing exposures.

6 References

Bernard, B. P. (Ed.) (1997) Musculoskeletal disorders and workplace factors: Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back Washington, D.C., U.S. DHHS.

Blood, R.P., Ploger, J.D., Yost, M.G., Ching, R.P., and Johnson, P.W. (2010). Whole body vibration exposures in metropolitan bus drivers: A comparison of three seats. J. Sound Vib. 329, 109–120.

Blood, R.P., Yost, M.G., Camp, J.E., and Ching, R.P. (2015). Whole-body vibration exposure intervention among professional bus and truck drivers: A laboratory evaluation of seat-suspension designs. J. Occup. Environ. Hyg. 12, 351–362

Bovenzi, M. (2009). Metrics of whole-body vibration and exposure–response relationship for low back pain in professional drivers: a prospective cohort study. International archives of occupational and environmental health, 82(7), 893-917.

Bovenzi, M. (2010). A Longitudinal Study of Low Back Pain and Daily Vibration Exposure in Professional Drivers. Ind. Health 48, 584–595.

Burström, L., Nilsson, T., and Wahlström, J. (2015). Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis. Int. Arch. Occup. Environ. Health 88, 403–418.

Cann, A. (2002) Predictors of whole-body vibration exposure in experienced by transport truck operators. Ergonomics, 2002. Thesis, Laurention University, Ontario

Cann, A., Salmoni, A. and Eger, T. (2004) Predictors of whole-body vibration exposure in transport truck operators. Ergonomics, 47(13), 1432-1453.

Cann, A., Vi, P., Salmoni, A. and Eger, T. (2003) An exploratory study of whole-body vibration exposure and dose while operating heavy equipment in the construction industry. Applied Occupational Environmental Hygiene, 18(12), 1999-2005.

CCOHS (2008) Vibration Introduction at:
https://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_intro.html

Dickey, J. (2016) Whole Body Vibration: What can we do to Reduce this Known Health Risk? Plenary lecture, Oct 25, Institute for Work & Health, Toronto.
https://www.iwh.on.ca/events/speaker-series/2016-oct-25

Dietze, B. (2020) Comparison of Whole-body Vibration Attenuation Properties Between Active and Passive Suspension Seats. Electronic Thesis and Dissertation Repository. 7277.
https://ir.lib.uwo.ca/etd/7277

Du, B.B., Bigelow, P.L., Wells, R.P., Davies, H.W., Hall, P., and Johnson, P.W. (2018) The impact of different seats and whole-body vibration exposures on truck driver vigilance and discomfort. Ergonomics 61, 528–537

Du, Bronson. (2016) Effects of seat suspension types on truck drivers' vigilance. MS thesis. University of Waterloo.

Eger, T., Contratto, M., and J.P. Dickey (2011) Influence of Driving Speed, Terrain, Seat Performance and Ride Control on Predicted Health Risk Based on ISO 2631-1 and EU Directive 2002/44/EC. Journal of Low Frequency Noise Vibration and Active Control. Vol.30(4) 291-312

Grandlund, J. (2018) Health Issues Raised by Poorly Maintained Road Networks, Roadex III, Swedish Road Administration Consulting Services, March 2008, p. 21

International Organization for Standardization (1997). ISO 2631-1: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part I: general requirements.

Johanning, E., Fischer, S., Christ, E., Gores, B., Landsbergis, P. (2002). Whole-body vibration exposure study in US railroad locomotives—an ergonomic risk assessment. American Industrial Hygiene Association Journal 63, 439–446.

Johnson, P. (2019) University of Washington, personal communication

Kim, J. H., Zigman, M., Aulck, L. S., Ibbotson, J. A., Dennerlein, J. T., & Johnson, P. W. (2016). Whole body vibration exposures and health status among professional truck drivers: a cross-sectional analysis. Annals of Occupational Hygiene, 60(8), 936-948

Kim, J.H., Dennerlein, J.T., and Johnson, P.W. (2018). The effect of a multi-axis suspension on whole body vibration exposures and physical stress in the neck and low back in agricultural tractor applications. Appl. Ergon. 68, 80–89.

Louwers, T. (2016) Thesis (Master's)--University of Washington, 2016-06

Mansfield, N. (2005). Human Response to Vibration (Boca Raton, Florida: CRC Press LLC).

Nitti R, De Santis P. (2010) Assessment and prediction of whole-body vibration exposure in transport truck drivers. Industrial Health ;48(5):628-637. DOI: 10.2486/indhealth.mswbvi-24.

Piette, A., & Malchaire, J. (1992). Technical characteristics of overhead cranes influencing the vibration exposure of the operators. *Applied Ergonomics*, *23*(2), 121-127.

Shibata, Nobuyuki, and Setsuo Maeda. (2010) Determination of backrest inclination based on biodynamic response study for prevention of low back pain. Medical engineering & physics 32.6 (2010): 577-583

Teschke, K., Nicol, A.-M., Davies, H., & Ju, S. (1999). Whole body vibrations and back disorders among motor vehicle drivers and heavy equipment operators: a review of the scientific evidence [R]. doi:http://dx.doi.org/10.14288/1.0048193

Tiemessen, I. J., Hulshof, C. T., & Frings-Dresen, M. H. (2007). An overview of strategies to reduce whole-body vibration exposure on drivers - A systematic review. International Journal of Industrial Ergonomics, 37(3), 245-256.

Village, J., Trask, C., Chow, Y., Morrison, J. B., Koehoorn, M., & Teschke, K. (2012). Assessing whole body vibration exposure for use in epidemiological studies of back injuries: measurements, observations and self-reports. Ergonomics, 55(4), 415-424.

Wikstrom, B., (1993). Effects from twisted postures and whole-body vibration during driving. International Journal of Industrial Ergonomics 12, 61–75

7 APPENDIX

7.1 Interview Questions – Field Study

Basic Information

Driver

Name ____

Employer ____

Address if they want study results

____ **Cab/ Tractor Information**

Manufacturer, model age ____

Suspension ____

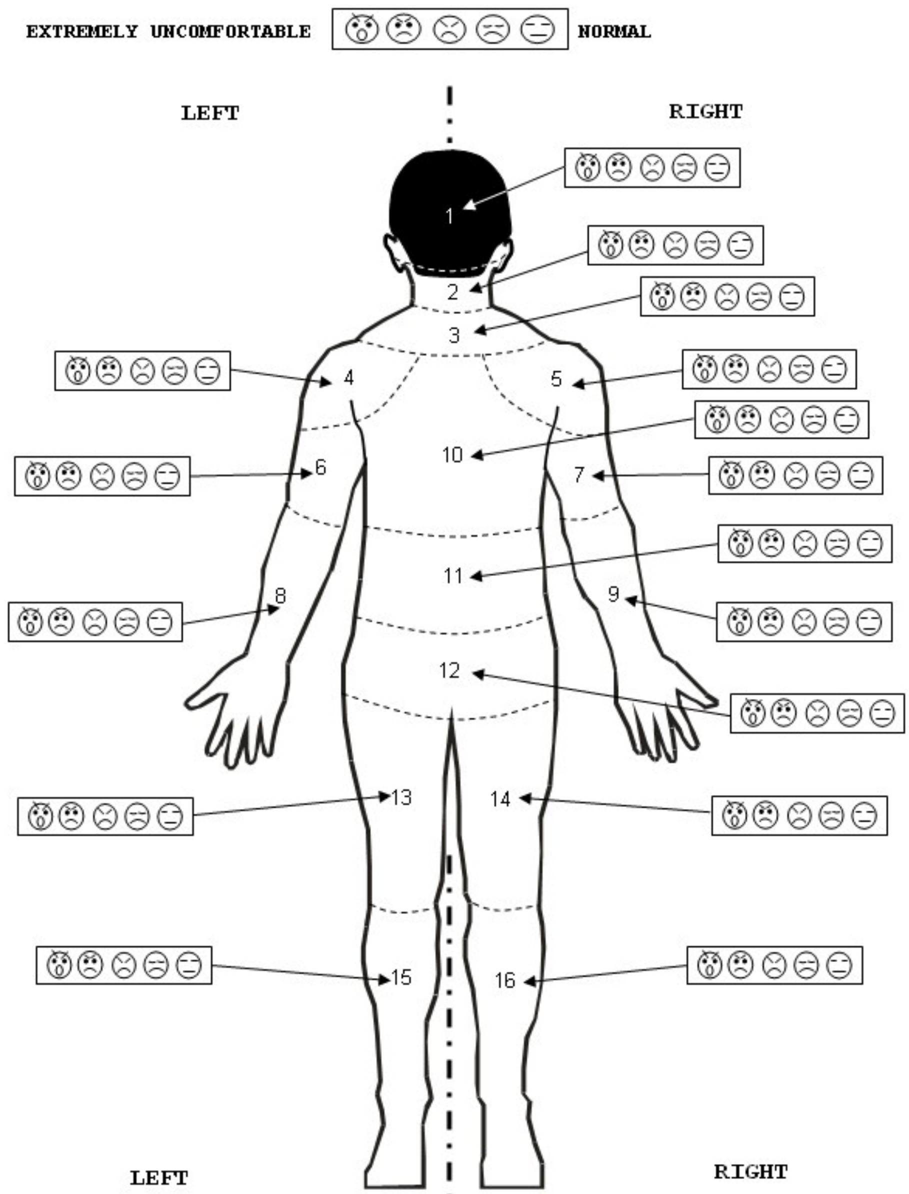
Mileage : ____

Trailer: ____

Manufacturer:____

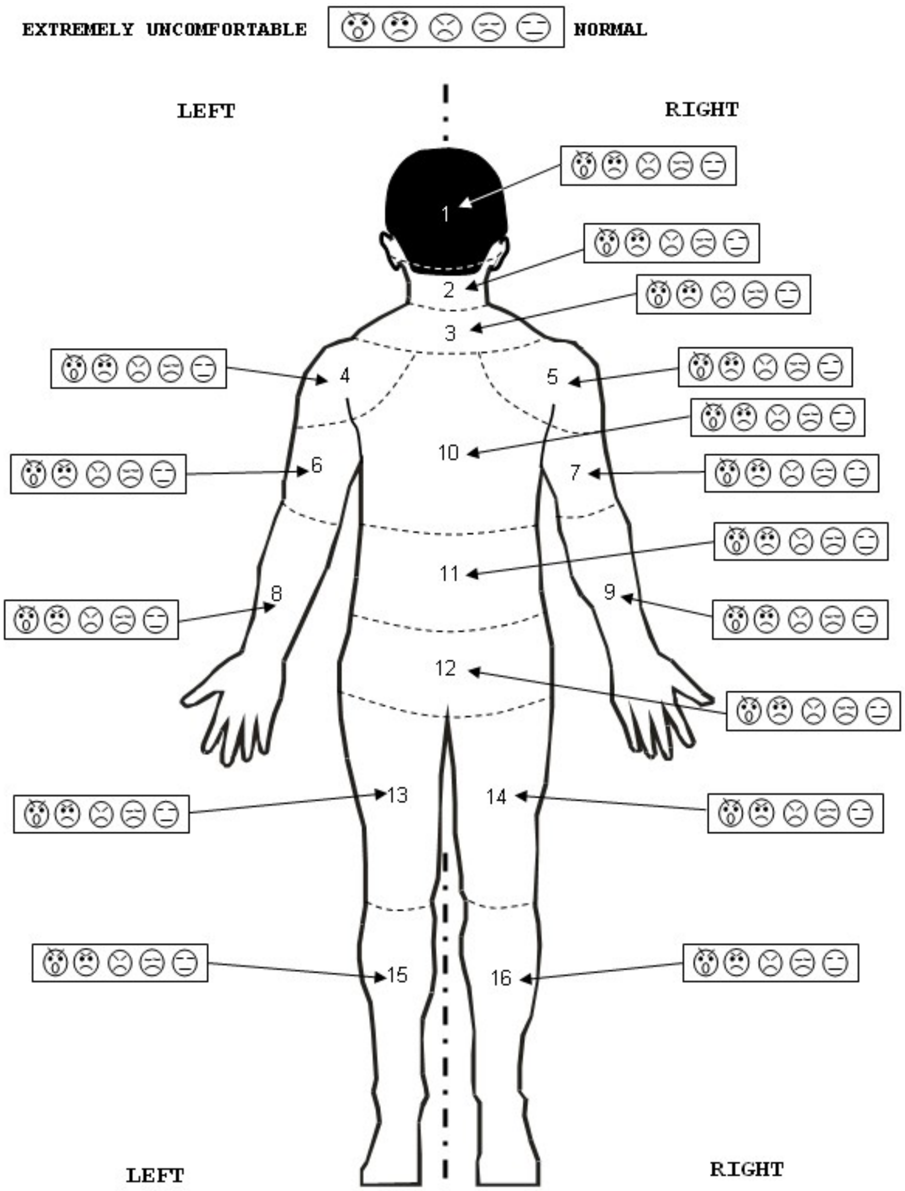
Current load: ____

Seat Manufacturer: ____


EXTREMELY UNCOMFORTABLE
NORMAL
LEFT
RIGHT
1
2
3
4
5
10
6
7
11
8
9
12
13
14
15
16
LEFT
RIGHT

7.2 Interview Questions – Truck Drivers

Introductions and consent
Completion of the body pain/comfort map



Complete section on comfort/pain map for areas identified as a problem
To allow us to complete our study we need a little bit of information:
How long have you been a truck driver?
How many hours a week do you work? How many miles/week?
When is the last time you drove your truck in Manitoba? What percentage of your time do you spend driving in Manitoba?
Now turning to your truck/tractor:
What percentage of the time do you drive the truck you are driving now? [the only truck you drive]

What kind of seat do you have?

- is it aftermarket or is the one that came with the truck

Do you own the truck?
What is the make of the truck?
Do you know the age of the tractor/truck?
What kind of suspension is installed?
What is the make of trailer?
What do you carry and do you know the weight?
In terms of the seating in your truck

- How comfortable is your truck seat?
- Do you sit on a pad or use additional support for your seat?
- Does vibration from your truck cause you to get a sore back? Become fatigued?
- Has someone shown you the ways you can adjust your seat [probe for ergonomist; OHS; seat manufacturer]
- Have you tried an anti-vibration seat?
- If you were to replace the seat in your truck, is it you or someone else who makes the decision about what seat to purchase? If it is someone else, do you have input into the decision?
- How often do you (or your company) replace the truck seat?
- What factors are considered when making a decision about a new seat (seat type for a new tractor or a replacement) [probe for cost, seat adjustments, comfort, durability, vib]
- Would information on which seats provide the most reduction in vibration be helpful to you or your company?
- How much extra would your company or you pay for an anti-vibration seat?

We collect some personal information that's helpful in the research – it is optional Have you had a WCB claim for a musculoskeletal disorder or disability related to your driving? Have you ever had medical treatment related a condition related to your work? What kind of disability?
How old are you?
What is your weight?
How tall are you?
May we call you in a few months to see if there have been any changes to seating in your vehicle?
At the same if you give us an address or email address I will forward the preliminary findings. This may help you if you are in the market for a new seat.

Thanks very much for your time.

7.3 Interview Questions – Trucking Company Managers

Interview Questions.
What is your primary activity? (long-haul, local deliveries, agriculture, manufactured products)
How are you organized?
Union/non-union?
How many staff?
How are people paid? (Hourly mileage)
Who pays for driver's licences?
What are your major issues with drivers?
Do you have a H&S staff person?
What kind of WCB claims?
MSD related claims?
Incentives/programs to improve health, safety, wellness?
Other health problems you have to deal with?
Do you get complaints about the amount of vibration? Any claims?
How do you make equipment decisions?
What evidence do you use to make decisions? How do you keep current?