Evaluation of a vibration measurement tool as part of a whole-body vibration management program in underground hard-rock mining

by

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Abstract

Prolonged exposure to whole-body vibration (WBV) experienced by mobile equipment operators requires routine measurement to manage the risk for numerous adverse health effects. The WBVpod is an affordable and purportedly accurate iPod application that could provide workers the means to regularly measure WBV exposure. The WBVpod was used simultaneously with a gold-standard vibration meter to determine the level of agreement between the two devices during laboratory and field trials. Furthermore, a pilot study that used the WBVpod and educational sessions among underground miners (n=7) and trainees (n=11) was conducted to determine how the WBVpod could compliment an intervention on perceived knowledge, as well as gaining feedback from the participants on the usability of the WBVpod.

The WBVpod displayed a high level of agreement with the gold standard device for all three axes (ICC: 0.92-0.97), with the vertical axis having the least bias (-0.015 m/s^2) but a wider limits of agreement (-0.136 – 0.106 m/s^2). The pilot study found a significant improvement in perceived WBV knowledge ($U=9.5$, $p<.05$), however discomfort was a common complaint when sitting on the WBVpod for extended periods of time.

The findings suggest that the WBVpod would be a valid tool to estimate WBV exposure. In addition, the majority of participants experienced an increase in perceived WBV knowledge and increased ability to measure WBV.

Keywords

Whole-body vibration, iPod application, validation, knowledge, usability

Co-Authorship Statement

Chapters 3 and 4 will be presented as manuscripts for publication in referred journals.

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Glossary

Abbreviations

A(8)	8-hour energy equivalent vibration total value
a_{wx}	frequency-weighted r.m.s. acceleration in the x-axis (ISO 2631-1)
a_{wy}	frequency-weighted r.m.s acceleration in the y-axis (ISO 2631-1)
a_{wz}	frequency-weighted r.m.s. acceleration in the z-axis (ISO 2631-1)
aRMS/wRMS	frequency-weighted root-mean-square acceleration
df	degree of freedom
FTV	foot-transmitted vibration
HAV	hand-arm vibration
HGCZ	health guidance caution zone
HVM	human vibration meter
IMU	inertial measurement unit
ISO	International Organization for Standardization
ISO 2631-1 (1997)	Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration – Part 1: General requirements
$k_{x,y,z}$	scaling factor for assessing axis-specific health risk (k= 1.4 for x & y axis; k=1.0 for z axis)
LBP	low back pain
LHD	load-haul-dump vehicle
MSD	musculoskeletal disorders
NSP	neck and shoulder pain
OHP	occupational health practitioner
r.m.s	root-mean-square
VATS	vibration analysis toolkit
VDV	vibration dose value
WBV	whole-body vibration
WBVpod	iOS application for measuring whole-body vibration
W_d	weighting factor applied to the x & y axes, as described in ISO 2631-1
W_k	weighting factor applied to the z-axis, as described in ISO-2631-1

Vibration Terminology and Definition

A(8): a simplified term for daily vibration exposure expressed in meters per second squared (m/s^2). Particularly useful in interpreting whole-body vibration exposures during the day.

Amplify: an increase in the amplitude and intensity of a signal.

Attenuate: a reduction in amplitude and intensity of a signal.

Control strategies: approaches to reduce the risk of adverse health effects from exposure to vibration; hierarchy of control is as follows: elimination, substitution, engineering, administration, and personal protective equipment (PPE).

Data logger: a portable, programmable data acquisition unit that can be attached on or near the subject being exposed to vibration.

Dominant frequency: the frequency at which a maximum value occurs in a spectral density curve

Frequency-weighted: modifies a wave-form according to a defined frequency-weighting. The reasoning behind this is that the human body is more sensitive to some frequencies compared to others.

Health guidance caution zone (HGCZ): defines a levels/zones of risk associated with a range of vibration exposure values. "For exposure below the zone, health effects have not been clearly documented and/or objectively observed; in the zone, caution with respect to potential health risks is indicated and above the zone health risks are likely."

Human vibration meter (HVM): an instrument used to measure human exposure to vibration; consists of a data acquisition device, a transducer (i.e. tri-axial accelerometer), and a seat pad.

IS0-2631-1: The International Standard for Mechanical vibration and shock- Evaluation of human exposure to whole-body vibration.

Load-haul-dump (LHD) vehicle: a type of mobile, earth-moving equipment used in the mining sector for mucking; also referred to as a scoop.

Resonance frequency: frequency at which resonance occurs; a point at which maximum displacement between organs and skeletal structures occur, resulting in stain/stress on the tissue involved.

Root-mean-square (r.m.s): the square-root of the averages of squared values for a set of data.

Scaling factors (k): a multiplying factor that is applied individually to each axis, and differs depending on what is being assessed (ex. health risks: kx and y: 1.4, kz: 1.0; comfort: kx,y,z: 1.0).

Transmissibility: the ratio of the vibration measured between two points (ex. between the floor and seat pan of a LHD).

Vibration: an oscillatory motion about a fixed reference point.

Vibration analysis toolkit (VATS): software used to derive various measures defined by the ISO-2631-1 (1997) standard for assessing health-related effects of vibration exposure.

Whole-body vibration (WBV): occurs when a surface that is supporting the human body is undergoing vibration, which is then transmitted to the part of the body in contact with the surface. The vibration can affect parts of the body near and remote to the site of exposure.

WBVpod: an iOS application used on an Apple device (iPod touch, iPhone) that measures vibration exposure (acceleration – m/s^2). Can then estimate health risk by estimating A(8) and VDV and compare against the HGCZ, and present to the exposed subject in an intuitive, and user-friendly manner.

Chapter 1

1 Introduction

It is estimated that 4-7% of Northern Americans and Europeans are exposed to potentially harmful levels of whole-body vibration (WBV) in the workplace (Bovenzi, 1996). Operators of mobile equipment, particularly those in the forestry, mining and construction sector, are exposed to vibration through surfaces supporting the human body, such as the backrest, seat pan, or floor. This is known as WBV: an oscillatory motion about a fixed point that travels through a mechanical structure; the oscillatory motion can be transferred to areas of the human body in contact with the mechanical structure. Health risks associated with WBV depend on a range of factors namely magnitude, duration, frequency and direction of the vibration exposure, as well as posture, seat dynamics, and operator experience (Griffin, 1990; Viruet et al., 2008).

1.1 Whole-body Vibration Exposure and Health Effects

A wide range of health risks have been associated with WBV exposure including gastrointestinal issues, circulatory disorders, reproductive disorders, impacts on motor process, and musculoskeletal diseases (MSD) (Seidel et al., 1980; Seidel 1993, 2005; Santos et al., 2008). According to the Ontario Ministry of Labour, MSDs are the most common type of workplace injury, accounting for 40.1% and 46.9% of all of the Ontario Workplace Safety and Insurance Board injury claims in 2013 for Schedule 1 and 2 employers respectively. Furthermore, 17% of lost-time claims pertain to low back pain (LBP) (WSIB, 2013). Epidemiological studies suggests that exposure to WBV is associated with an increased risk for LBP (Bovenzi & Betta, 1994; Lings & Leboeuf, 2000; Seidel, 2005). While the pathology of LBP is unclear, it is postulated that WBV increases the load placed on the spine due to changes in posture as the muscles respond to the vibration signals (Santos et al., 2008; Seidel et al., 1980). This increased load may translate to micro fractures in the endplates of the vertebrae, usually in the lumber/thoracic region, leading to a callus forming over the damaged areas. These calluses block the diffusion of nutrients to the intervertebral discs, leading to starvation and eventual degeneration. Disc degeneration itself leads to spinal disorders: herniated disc, or a pinched nerve (sciatica), which is perceived as LBP (Sandover, 1983).

1.2 Mobile Equipment Operator's Exposure to WBV

Occupational WBV exposure is of greatest concern within industries that use mobile, earth moving equipment, namely construction, forestry and mining. From forklifts and backhoes, to graders and load-haul-dump (LHD) vehicles, the shift from hard, physical labour to a more sedentary and mechanized practices has brought WBV exposure to the forefront of occupational health and safety (McPhee, 2004). Operators of mobile equipment in the mining industry, such as LHD operators, are an at-risk group for vibration-related health problems from WBV exposure (Eger 2006, 2011). Although a dose-response relationship may not always be evident (Lings & Leboeuf-Yde, 2000), the fact remains that operators of mobile equipment show a higher prevalence of WBV-related health issues (Bovenzi, 1996). Therefore, a new approach is needed that will allow routine monitoring of WBV, with the added benefit of potentially increasing a worker's willingness to adopt the best practices to limit health risks (Porru et al., 1993; Village et al., 2012).

1.3 Assessment of Whole-body Vibration Exposure

WBV is typically measured using a tri-axial accelerometer, which measures the magnitude of acceleration of the vibration signal in the x-, y-, and z-axes (fore/aft, lateral, and vertical respectively). The readings from the accelerometer are collected by a data logger that is with the operator in the cab during operation. The data are then uploaded to a software program of choice which applies the appropriate weighting and scaling factors outlined by the International Organization for Standardization (ISO), with the end result being a daily-dose value that can be compared against a health guidance caution zone (HGCZ) (ISO-2631-1, 1997) (Figure 1.1). For further information on ISO 2631-1 please refer to section 6.4 of Appendix A.

Current vibration measurement is expensive ($4,500-10,000) and requires technical expertise, resulting in infrequent vibration measurements. These gaps in exposure data are a major roadblock in determining a clear dose-response relationship between WBV and health effects. (Burgess-Limerick & Maslen, 2012; Thalheimer E., 1996; Village et al., 2012). As such, many epidemiological studies that cannot directly measure an individual's vibration exposure rely on hours or years of operation (indirect measurement), or simply compare drivers (exposed) to officer workers (control, unexposed). Consequently, using indirect measures of vibration exposure for an operator may not provide a true representation of their actual vibration exposure and subsequent health risks. Thus there is a need for a more simplified method of measurement. In 2014 an iOS application for an iPhone or iPod was developed to enable WBV measurement: WBVpod (Burgess-Limerick & Westerfield, 2014).

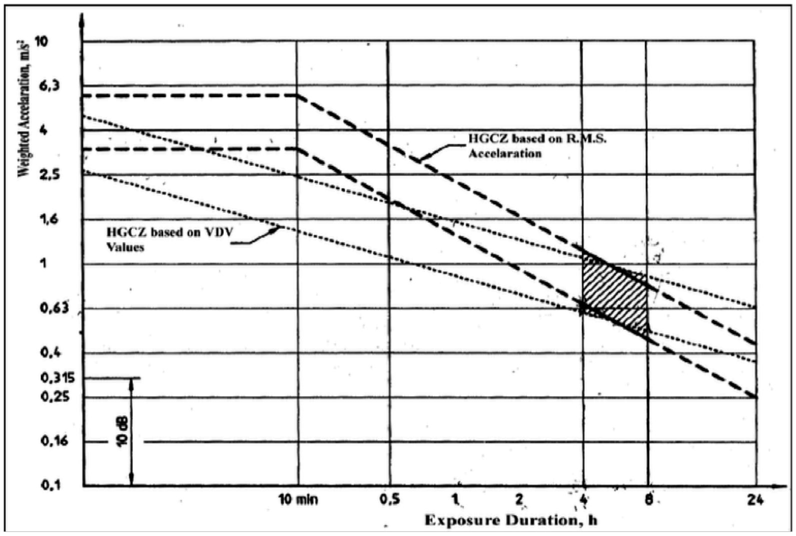

Figure 1.1 The ISO 2631-1 WBV exposure guidelines based on amplitude and duration (Annex B: Figure B1 in the ISO 2631-1 (1997)).

1.4 Thesis Outline

The purpose of this research is two-fold. First, to determine the validity of the WBVpod against a gold-standard tri-axial accelerometer and data logger system for WBV measurements. Second, to determine how the use of the WBVpod, when combined with three vibration education sessions, will affect perceived knowledge of WBV topics (i.e. health effects and control strategies).

The first objective will be accomplished via a laboratory and field study. The objective of the laboratory phase is to validate the WBVpod against the gold-standard method under simultaneous exposure to WBV profiles, generated by a vibration simulator. In relation to previous evaluations of the WBVpod (Wolfgang et al., 2014; Wolfgang & Burgess-Limerick, 2014; McGlothlin et al., 2016) the comparison trials in this study will include a wider range of frequencies, high acceleration amplitudes, as well as the operation of an LHD vehicle in underground hard rock mining. The generated profiles will be derived from previous field measures of mobile equipment in forestry, mining, and construction sectors. The profiles of the vibration exposures will involve high amplitudes in at least one of the translational (x, y, z axes) or rotational (roll, pitch, yaw) axes of motion. In addition, random sinusoidal vibration exposures will also be tested. Resultant data from the WBVpod and gold standard measurement system will be compared. Between-device agreement will be examined using intraclass correlation (ICC 2,1) where a coefficient of 0.7 or greater corresponds to high correlation. In addition, Bland-Altman plots will be constructed to further evaluate the level of agreement between the two devices by plotting the mean differences (bias) with 95% confidence intervals, and percent differences. A selected number of trials will be completed during the operation of underground mining equipment to compare vibration output measured with the WBVpod to vibration measurements obtained with the gold standard equipment.

The second objective will be conducted through field-testing involving underground mobile mining equipment operators. Participants will be given a baseline survey to assess their perceived knowledge with regards to vibration, health effects and control strategies. Participants will be evaluated using a pre-post, within-subject design. In between the pre-and post-measurements participants will undergo an intervention. The intervention will consist of a tutorial on the WBVpod, as well as educational pieces on health effects and control strategies. After a four- to six-week period the participants will be asked to complete the perceived vibration knowledge survey again, and differences in knowledge will be determined. In addition, feedback on the usability of the application and educational pieces will be collected.

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Chapter 2

2 Literature Review

This chapter will provide a summary of WBV exposure in the workplace, its associated health effects, methods of measurement, and the use of a simple iPod application tool (WBVpod). The aim of the chapter is to provide justification for the current research.

2.1 Vibration Basics

Vibration is defined as a mechanical movement that oscillates about a fixed point. Humans are exposed to vibration when they come into contact with the oscillating object (coupling), such as the seat pan of a LHD, or the platform of a scissor-jack lift. Several characteristics of interest when measuring vibration are the amplitude, frequency, direction, and duration. The amplitude is the magnitude of the vibration signal and is described by three qualities: displacement (m), velocity (m/s), and acceleration (m/s^2). For the purpose of measuring WBV the amplitude of the vibration signal is defined by acceleration (m/s^2; G) (Griffin, 1990), or 'bounce height'. The frequency is the cycles per second (units = Hz; hertz) or how many times oscillations occur in a given period of time within the vibration signal (Figure 2.1, right image). The direction of the vibration signal is also taken into consideration. The vibration signals encountered in the real world are composed of an array of vibration signals occurring at various frequencies and directions (Figure 2.1, left image). Vibration signals are usually measured in the x-, y-, and z-axes, which translate to fore-aft, lateral, and vertical directions respectively. However, it has recently become common practice to measure vibration within 6 degrees of freedom (6df): x, y, z, roll, pitch, and yaw (Dickey et al., 2010; Dickey et al., 2008; Oliver et al., 2010). Thus, a focus is directed at where the vibration is being applied, in what direction, and for how long (continuous, intermittent, rest periods).

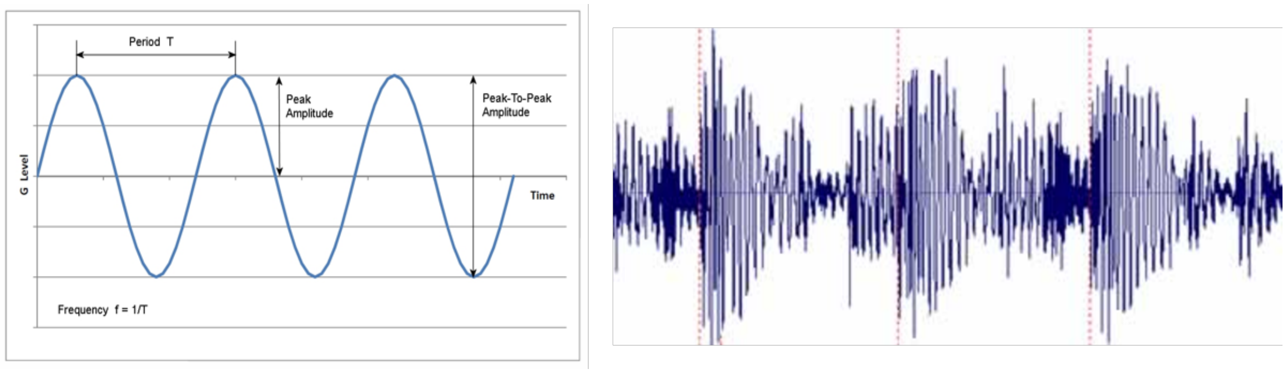

Figure 2.1 Simple (left image) and random (right image) vibration waveforms.

The factors evaluated when assessing human response to vibration can be categorized into external and internal factors. External factors include the frequency, magnitude, direction, and duration of vibration, as well as seating, temperature, and noise. Conversely, internal factors associated with WBV include age, sex, height, health, experience, job satisfaction, posture (neutral vs. non-neutral), and leisure activities (Griffin, 1990; Bovenzi, 2005). Overall, human response to vibration is multifactorial.

2.1.1 Resonance Frequency

The etiology of health problems associated with vibration exposure relates to the response of the human body to vibration, which is based on resonance frequencies. The human body has multiple resonance frequencies depending on the segment of the body being assessed (Table 2.1) (Duarte et al., 2002; Wisner et al., 1964). Resonance frequency is defined as the point at which maximum displacement between organs and skeletal structures occurs, thereby placing strain on the body tissue involved. The resonance frequency of most organs is between 1-10 Hz (Noorloos et al., 2008). As such, vibration assessment is based on the area of transmission/response: hand-arm vibration (HAV), foot-transmitted vibration (FTV), and whole body vibration (WBV). The main differences between these types of exposure are the response of the body parts, or resonant frequencies. A greater response at higher frequencies is observed in HAV (20-40 Hz) and FTV (50 Hz range, with the toes being closer to 120 Hz) (Dong et al., 2004; Forta et al., 2011; Goggins, In press), while WBV frequencies are in the range of 1-20Hz (Mansfield & Griffin, 2002; Thalheimer, 1996). In regards to the workplace, the input frequency at the seat may vary compared to the frequency at the head due to differences in transmissibility: a measure of the body's ability to attenuate or amplify vibration input (Padden & Griffin, 2002). Thus an input vibration may not be at the resonance frequency of a certain body part (ex. eye), but depending on the changes in transmissibility, the vibration signal may be at the resonance frequency once it reaches the body tissue of interest.

Table 2.1 Summary of resonance frequency ranges of the various body sections

Body Part	Resonance Frequency (Hz)
Eyeball, intraocular structure	20-90
Shoulder girdle	4-5
Spinal column	10-12
Head	20-50
Chest wall	50-100
Abdominal mass	4-8
Legs	2-20

2.2 Health Effects

Numerous studies have demonstrated that prolonged exposure to WBV places workers at an increased risk for health problems (Bovenzi 1996, 2005; Cann et al., 2004; Kuijer et al., 2014; Pope et al., 1998). Common health effects associated with vibration exposure include gastrointestinal issues (gastritis, ulcers), cardiovascular and respiratory effects, hormonal changes, fatigue in motor or reduction in motor performance and ability, headaches, nausea, vision problems, and hearing loss (Pope et al., 2002; Bovenzi et al., 2005; Bovenzi, 2009).

However, the most common health complaint associated with WBV is low back pain (LBP) (Seidel & Heide, 1986).

LBP is defined as the perception of an ache, pain, or stiffness in the lower part of the lumbar spine. Oftentimes LBP is a symptom and may not be accompanied by observable physical changes (i.e. lesions) in the spine and musculature (Seidel & Heide, 1986; Cooper et al., 1992). However, early degeneration of the lumbar spinal system and herniated discs has been reported among professional drivers (Huschof & van Zanten, 1987). Accelerated disc degeneration may arise from vibration-induced reduction in nutritional support to intervertebral disc (Holm & Nachemsan, 1983). It is postulated that WBV increases the load placed on the spine due to changes in posture as the muscles respond to the vibration signals (Santos et al., 2008; Seidel et al., 1980). This response becomes more pronounced as the vibration signal(s) draw nearer to the spines resonant frequency (Wilder et al., 1982). These increased loads would translate to micro fractures in the endplates of the vertebrae, usually in the lumber/thoracic region. Calluses would form over the damaged areas, and block the diffusion of nutrients to the intervertebral discs. The end result would be starvation and an increased rate of eventual spinal degeneration (Sandover 1981, 1983). This is just one of several theories on how vibration leads to spinal damage. Other theories include fatigue-induced failure of the annular lamellae and consequent nuclear prolapse, or muscular insufficiency with height loss of intervertebral spaces causing instability and strain fracture (Frymoyer & Pope, 1978; Sandover, 1983; Seidel & Heide, 1986).

In addition, WBV is believed to influence LBP through postural control (i.e. stability). Stability refers to the ability of a system, such as the spine, to return to its neutral position after a change in position due to external forces. Spinal stability depends in part on the visco-elasticity of the spinal tissue, which in turn relies on passive tissue support and neural control (reflex) to maintain a neutral posture. WBV is thought to influence the passive tissue support by changing the visco-elasticity of the tissue through creep deformation of the intervertebral discs (Keller & Nathan, 1999). This deformation (compressions) of the intervertebral discs translates to a decrease in passive stiffness and diminished stability. Additionally, neuro-sensory functions (reflexes) may be delayed by prolonged WBV exposure. Ultimately these influences on visco-elasticity of the spinal tissue and neuro-sensory function are associated with a decrease in spinal stability and an increased risk for injury (Arora et al., 2015).

Despite the findings of an association between LBP and WBV exposure, LBP is a multifactorial disorder, involving both occupational and non-occupational factors (Lings and Lebeouf-Yde, 2000). Such factors may include climatic conditions, previous back injuries, amount of manual/physical work, poor posture or prolonged sitting, and psychosocial conditions (Viruet et al., 2008). Consequently, developing an exposure response relationship based solely on WBV exposure would be challenging.

2.3 Epidemiological Studies

With approximately 4-7% of the North American and European workforce being exposed to potentially harmful levels of vibration (Bovenzi, 1996), individuals at high risk for WBV exposure include professional drivers within the agricultural, construction, forestry, and mining industries. As such, these industries experience a higher prevalence of LBP (when comparing workers exposed to WBV vs. unexposed workers), missed days, absenteeism, and turnover rate (Bovenzi, 2005). Bovenzi (1996) investigated both the cumulative lifetime occurrence of LBP symptoms between drivers of tractors and buses (exposed) versus controls (unexposed). Bovenzi found that the duration of exposure to WBV was related to LBP more consistently than vibration magnitude when estimating cumulative lifetime exposure. In addition, Bovenzi et al. (2006)

monitored the prevalence of LBP in 598 professional drivers over a range of equipment - excavators, forklifts, rock crushers, as well as garbage trucks and buses - within various industries: marble quarries and laboratories, dockyards, paper mills, and public utilities. Exposure to WBV was then compared to a control group of 30 fire inspectors (not exposed to WBV), with an emphasis on musculoskeletal risk factors. The study found that both the intensity and disability from LBP increased as cumulative vibration exposure increased. However, WBV was not the sole association, as age and history of back accidents also influenced LPB prevalence.

While epidemiological studies have identified associations between WBV exposure and health effects (notably LBP), it is not the only factor to influence health effects. Other extenuating factors that influence an individual's risk include work posture, road conditions, ergonomic factors, vehicle maintenance, repetitive movements, and high force demands (Griffin, 1990). Thus the multifactorial nature of LBP suggests that extenuating factors may have an additive effect alongside WBV exposure in their influence on spinal stability and incidence of LBP (Tiemessen et al., 2007; Bovenzi, 1996).

The multifactorial nature of LBP (and other MSD) is highlighted by a prospective cohort study by Bovenzi (2015). It was observed that neck and shoulder pain (NSP) among professional drivers was significantly associated with cumulative WBV exposure. However, work that involved heavy lifting, working with the hands over shoulder level, and driving with the trunk in a bent or twisted position were also significantly associated with incidences of NSP. Interestingly, psychological influences such as feelings of limited job decision, low social support, and job dissatisfaction were also significantly associated with incidences of neck pain (Bouter et al., 2001). While the mechanisms by which psychological factors influence neck and shoulder pain is unclear, it demonstrates that the origin of occupational diseases are multifactorial (both physical and psychological), and are not limited to WBV exposure alone (Bovenzi, 2015; Cann et al., 2004; Pope et al., 1998; Bovenzi, 1996). Nevertheless, intervention strategies to eliminate or reduce workers' exposure to WBV are warranted in combination with other strategies (ergonomic, social support, engineering) to protect the workforce from occupational diseases. Kuijer et al. (2014) reported that non-specific (i.e. caused by problems with structures in the back rather than cancer, infections, factures, or inflammation) lower back pain (nLBP) was the second most common reason for sick leave in the Netherlands, in which 50% of the workers on sick leave attribute these complaints to their work. While less than 1% of nLBP was attributed to WBV, 35% of the WBV-nLBP population experience sick leaves greater than 2 weeks (Kuijer et al., 2014).

2.4 Methods of Measurement

The factors of interest when measuring WBV are: frequency, magnitude, direction, and duration. Vibration magnitude is measured using a tri-axial accelerometer and is reported in (m/s^2). Direction pertains to the x (back-to-front), y (left to right), and z (vertical) axes; duration is measured in hours; and frequency in cycles per second (Hertz; Hz) (ISO 2631-1, 1997). Vibration data are typically processed in accordance with ISO 2631-1 with outputs for health risk determination being frequency-weighted root-mean square (*a*r.m.s.) acceleration or vibration dose value (VDV). Please refer to Appendix A for more information.

2.5 WBV Field Measurement

2.5.1 Current Methods

Field measurements of WBV typically require three pieces of equipment: a tri-axial accelerometer, data-logger, and a seat pad. The tri-axial accelerometer is mounted to the vibrating surface. For a mobile equipment operator, the mounted accelerometer is secured to the seat surface such that it sits between the seat pan and buttocks, and captures the magnitude of acceleration in the x, y, and z-axes (ISO 2631-1, 1997). The accelerometer acts as the transducer, converting the mechanical vibration signal into an electric output to be picked up by the data logger. The data logger proceeds to convert the electric signal into a digital read-out, which involves various condition and filtering processes. The recommended sampling rate is 500 Hz, or at least 3 times the highest frequency of interest (Mansfield, 2005). Additional information – task being performed, equipment type, operating speed, and road condition – can also be collected as these factors can influence vibration exposure.

2.5.2 WBVpod

A fifth-generation iPod Touch (Apple Inc., Cupertino, CA) with an iOS application (WBV v2.3, ByteWorks Inc.) makes up the WBVpod. The application is used on a 16GB iPod touch (123mm x 59mm x 6mm, 86g) that uses the built-in STM LIS302DL accelerometer (STMicroelectronics, Geneva, Switzerland) to record vibration. The WBVpod provides three-dimensional 16 bit data output that is configured to a range of +/- 2G, with a maximum sampling rate of 100 Hz. However, sampling at 100Hz results in a bi-modal distribution of inter-sample intervals (ISS). When set to a sampling rate of 99Hz, an actual sampling rate of 89 Hz occurs (Wolfgang & Burgess-Limerick, 2014). Compared to the sampling rates of the gold standard of 1000 Hz, the main source of inaccuracies in estimating WBV exposure will stem from these limitations of the sampling rate. Despite these limitations, preliminary studies comparing the accuracy of the WBVpod against the gold standard were promising. Wolfgang et al., (2014) compared 58 pairs of measurement from heavy vehicles and determined that the WBVpod can be used to measure WBV amplitude with a 95% confidence of +/- 0.09m/s^{2}r.m.s. Furthermore, the vertical direction (z-axis) was the most accurate compared to the x and y-axes (limit of agreement: +/- 0.063 m/s^2 r.m.s), which tends to be the dominant direction when assessing vibration under the ISO-2631-1 guidelines. McGlothlin et al., (2015) also compared pairs of measurements for a variety of vehicles at a surface coalmine, and had similar 95% confidence intervals of +/-0.07 m/s^2 r.m.s for the vertical direction.

Once the vibration data are filtered and weighted the WBVpod calculates the r.m.s and VDV measures. These measurements are compared against the health guidance caution zone (HGCZ) with a visual display: data plotted in the green section represents exposure below the HGCZ; yellow within the HGCZ; and red above the HGCZ (Figure 4.2 in Chapter 4). In addition, the WBVpod displays the frequency-weighted r.m.s for all three axes, the time (hours) to exceed the 8-hour HGCZ at current exposure values, as well as the vibration dose value and 8 hour equivalent dose value for all three axes.

A recent laboratory study comparing outputs measured with the WBVpod and a gold standard inertial measurement unit (IMU) were also promising (Ji et al., 2014). However, the authors reported that some issues in sampling variability were present, and suggested that further verification tests be performed with the WBVpod before it is widely distributed for workplace applications.

Managing WBV-related risks begins with observing/identifying potential risk factors in the field, developing innovative interventions (i.e. control strategies) in the lab, and integrating the interventions back into the field; evaluation after integration is also important, as it will help determine the efficacy and effectiveness of the intervention. With a field-to lab-to field approach the goal is to develop guidelines and management programs in an attempt to eliminate or reduce health risks associated with WBV exposure. While the tri-axial accelerometer and accompanying data-logger can provide an accurate estimation of the magnitude and direction of vibration exposure through its high sampling rate, the cost and complexity of the equipment limits its usability in the field, as well as providing workers with timely feedback that is easy to interpret. The WBVpod was designed to capture vibration data, albeit at a lower sampling frequency. Both the WBVpod and tri-axial accelerometer/data-logger are capturing the same data, at the same location, under similar guidelines (ISO 2631-1, 1997); however, the WBVpod is unique in its straightforwardness and instantaneous feedback. The differences between the devices – such as sampling rate – means that while both devices are measuring the same variable, the output of from each device may differ. This difference could translate to uncertainties in the actual level of vibration exposure and degree of health risk of a worker. Thus, the WBVpod must be validated by comparing the outputs of the two measuring devices based on vibration profiles in the laboratory and field setting.

2.6 Field Studies in Mining

Mining practices have transitioned from heavy physical labour to a more sedentary, mechanized approach. While such practices have been a boon to productivity and revenue in the mining sector, this mechanization has resulted in workers being exposed to high levels of WBV (Bovenzi, 1996), particularly among operators of heavy equipment: LHD, dozers, graders, and front-end loader to name a few (McPhee, 2004). The epidemiological field studies in Table A2 of Appendix A suggest that workers exposed to high levels of vibration will be at an increased risk for LBP.

Several field studies have identified numerous factors that influence vibration exposure including terrain, vehicle speed, seat performance, and haulage capacity (Eger 2006, Eger 2011, Eger 2013, Village 1989) (Appendix A, Table A1). Industry and researchers can now target these factors to develop control measures such as reduced driving speeds, seat systems to attenuate vibration, and road maintenance programs.

2.6.1 Control Strategies

Control or preventative strategies are designed to manipulate factors that influence both WBV exposure and overall LBP risk, and can therefore have broader applications (ex. posture or prolonged sitting). These strategies typically fall under two categories: design considerations, and skills and behaviours. The two categories can be further broken down into a hierarchy of control strategies: elimination, substitution, engineering, administrative, and personal protective equipment (PPE).

Most strategies for reducing WBV exposure tend to focus on design (engineering) considerations, which includes cab suspension, seat suspension, or tire choice, and can take a long period of time to implement into the workplace (Goldenhar et al., 2001). However, the second category of skills and behaviours (ex. work patterns, decreased driving time and speed, and physical exercise) can be less expensive, and can be implemented to bridge the time period required to identify and implement engineering solutions (Tiemessen et al., 2007). In 2006 Hulshof et al., carried out a study whereby an intervention program consisted of both design considerations - floor and vehicle maintenance, type of seat, seat suspension, and tires - and skills/behaviour - driving style, speed, seat adjustment, track conditions, working schedules, and level of fitness (intervention groups were not separated). Overall, the experimental groups that took part in the intervention programs experienced a slight, yet not significant, reduction in WBV exposure over a 1-year period. Several possibilities for the slight (not significant) decrease included a positive influence on company policy, attitude and driving behaviours towards WBV, as well as increased knowledge among OHS practitioners and managers.

When considering the types of control strategies to implement in a workplace, it is important to address both the magnitude and duration of vibration exposure (Tiemessen et al., 2007). If we consider the Equation (1) for the commonly used dose values (units are in meters per second squared) where a_w is the frequency-weighted acceleration and t is the total duration, it is clear that the acceleration raised to the power of four is a major influence. However, the factor of time should be taken into consideration as well, suggesting that a combined strategy approach would result in a greater WBV exposure reduction (Tiemessen et al., 2007). While there is no conclusive evidence for either category on its own, a combination of both design consideration and skills/behaviour strategies may be the most effective approach in reducing WBV exposure (i.e. a multidisciplinary approach for a multifactorial problem) (Hulshof et al., 2006)(Tiemessen et al., 2007).

$$Dose\ value = \int a_w^4 * t \quad (\mathrm{m/s^2}) \tag{1}$$

2.6.2 Studies on Field Intervention to Limit WBV Exposure

A controlled pre-test-post-test study by Tiemessen et al. (2009) measured vibration exposure after introducing intervention programs to forklift drivers among several companies. It was hypothesized that a more personalized approach, by having workers and occupational health professionals (OHP) set agreements on control measures, would result in a significant decrease in WBV exposure. Although a lack of significant differences between the intervention and control groups were observed, 63% of drivers who were more than 50% complaint on the agreements set by the OHP experienced a reduction in WBV exposure. Major limitations of the study included the uncertainties in WBV exposure calculations, as well as the practicality of the agreements set by the OHP. For instance, decreasing driving speed is known to be an effective control measure in reducing WBV exposure (Eger et al., 2011; Village et al., 1989). However, in a high-pressure work environment driving slow maybe seen as an impediment, and unlikely to be practiced. Despite the overall lack of success of this intervention strategy, having OHPs and workers come to an agreement on which control strategies to follow may have potential in that it includes the worker in the decision-making process. The reality is that control strategies are successful only if there is compliance. The question now is, how to achieve compliance?

The education of operators for management of WBV exposure has seen some success in the field. Langer et al. (2012) demonstrated the influence of education on a group of backhoe loader operators by providing short educational segments on WBV exposure and eco-driving. Tasks were completed before and after the short education segments, whereby WBV exposure, fuel consumption, and duration were measured for each task. Subsequently, tasks performed after receiving education had lower WBV exposure and lesser fuel consumption. These findings demonstrate that education has the potential to lead to a reduction in WBV exposure, and would be an important component of any vibration management program (Langer et al., 2012). However, whether or not the operators who underwent the education continue to use the techniques and practice long after it was shown to them is a matter of compliance, as experienced by Tiemessen et al. (2009). While there is no consensus on an adequate follow-up period for refresher training (Ministry of Labour, 2015), perhaps a worker may be more likely to maintain certain behaviour to lower their exposure if they could routinely evaluate their exposure on a daily basis by using a type of personal WBV dosimeter. Nonetheless, this compliance dilemma may illustrates the need for all members of the workplace (managers, supervisors, workers), to be routinely informed of the best practices available, so that practices of decreased driving speed or planning a work route (least distance travelled) become second nature.

The ability for direct, routine measurement of whole-body vibration exposure is hindered by the financial cost and technical complexity of the equipment (Thalheimer, 1996; Wolfgang & Burgess-Limerick, 2014). Therefore, predictive models of WBV exposure have been investigated due to the costs and practicality issues of direct measurement. A study by Village et al. (2012) investigated the use of observed and self-reported data against direct measurement methods for vibration exposure (daily exposure values: A(8), a*w*). The self-reported model explained 60% of the variance observed, which means much of the variability in the vibration was not explained (Village et al., 2012). This suggests that alternatives to the current methods of WBV measurement are necessary for epidemiological studies. An improvement in the accessibility and feasibility of direct WBV measurement would help in developing dose-response relationships for various health risks (ex. pain or injuries) (Village et al., 2012).

The potential of the WBVpod is instrumental in that it may ameliorate some of the difficulties, such as cost and technical complexity, that come with direct measurement of WBV (Wolfgang &

Burgess-Limerick, 2014). A preliminary evaluation of the WBVpod by Leduc et al., (2014) compared the exposure values recorded with the WBVpod and a current gold standard tri-axial accelerometer and data logger system for urban bus passengers. On average the WBVpod correlated strongly with the measurements from the gold standard measurement system with absolute error for the x-, y-, and z-axes reported as 5%, 9%, and 9% respectively. While the initial findings are promising, further evaluation of the WBVpod against a wider range of vibration frequencies, higher magnitudes of acceleration, and during the operation of a LHD vehicle are needed before introducing the device as a tool for daily measurement of WBV in underground hard rock mining.

2.6.3 Interventions: Strategies and Methodological Considerations

There are four elements a researcher should consider when designing, implementing, and evaluating an intervention: intervention content, implementation context, implementation process, and target outcomes (Karanika-Murray & Biron, 2014).

The content of an occupational health and safety (OHS) intervention requires the researcher to consider the types of interventions and how they will be presented to the target population. The types of interventions can be classified into 3 broad categories: engineering, administrative, and personal. Engineering controls focus on the physical environment, such as seat suspension; administrative interventions tend to focus on procedures and policies, which include worker involvement and empowerment, goal setting, and feedback on behaviour; personal interventions target worker behaviour, education, and training (Zwerling et al, 1997). While no single type of intervention may be effective on its own, many OHS programs use a multifactorial intervention approach (Tiemessen et al., 2007). For example, the implementation of an engineering control may require training and behavioural changes to be effective (Parenmark et al., 1993). Thus, the type and quality of education and training that accompanies control strategies require consideration.

Educational methods for OHS interventions range in their level of engagement. Lesser methods that are the least engaging are information-based (presenting the facts); may include lectures, videos, or pamphlets (Burke et al., 2006). Moderate engagement provides knowledge of results and provides feedback on performance; includes computer-based instructions, modules, and workbooks, which are a staple in OHS training. The most engaging methods focus on development of knowledge, and are designed to modify behaviour (i.e. adopt the safest work practices) (Anderson, 1990; Bandura, 1986). The most engaging educational methods include observation of a model and/or participation in a model or practice (ex. simulations).

The goals of occupational health safety training are to increase safety knowledge, which in turn will lead to adoption of safe behaviour, with the outcome being elimination or reduction of the hazard of interest. Nowadays occupational health and safety training is frequently conducted through computer-based instruction (moderate engagement). The benefit of this modest engagement method is large-scale knowledge transfer. However, if the goal of OHS training is to eliminate or reduce risk and injury through changes in behaviour, then the most engaging methods of training: observation of a model, modeling or practice, and two-way dialogue between trainer and trainee would be the most effective. The underlying theme in each of these methods is that it requires active participation (engagement) by the trainee. A meta-analysis by Burke et al. (2006) found that in a given study, a randomly selected individual from the most engaging training group would have a greater probability (0.74) of having a higher level of knowledge acquisition compared to an individual randomly selected from the least engaging training group. This further reinforces the importance of the method in which workers receive health and safety training. However, when the outcome of interest shifts from knowledge acquisition to behavioural performance, all levels of engagement become comparable in overall means of effectiveness. The authors postulate that the complexity of the task could be an extenuating factor in the sense that routine tasks (such as applying sunscreen or wearing a seatbelt) tend to be paired with less engaging training methods, whereas more complex methods are grouped with more advanced work activities.

The success of an OHS intervention is also dependent on the context and process of implementation. Factors such as applicability to small business versus larger corporations, and gaining support of management and workers (key stakeholders) can dictate the successfulness of an intervention. An OHS intervention that requires a network of representatives (ex. ergonomic representatives from maintenance, workers, and engineering staff), or is perceived to have a negative influence on productivity, wages, and control of work processes may lack the feasibility and applicability to be effective (Zwerling, 1997). These issues can be avoided if the key stakeholders are included in the planning and implementation of the intervention (ex. selection of intervention, and recruitment of subjects) (Goldenhar & Schulte, 1996) and if the case for business can be made; the intervention will lead to fewer absenteeism/lost-time injuries and a more productive workforce (LaMontagne et al., 2015).

Lastly, the ability to evaluate the effectiveness of an intervention is dependent on the study design and the target outcomes. The ideal design would be based on a randomized controlled trial (RCT) approach, whereby the observable effect of the intervention would be distinguishable from all the other confounding variables and changes that could influence the outcome of interest (ex. LBP). However, a RCT approach has certain methodological issues when carried out in the field, most notably randomization and study group contamination.

Randomization becomes impractical when measuring events that develop over a longer period of time (ex. MSD), requiring large samples size and long follow-up periods to obtain enough statistical power. Likewise study group contamination can be difficult to avoid, as an intervention in a workplace is bound to affect more than one individual. Thus, the amount of time and money required to conduct such a large-scale study can be more than anyone is willing to undertake (Cook & Campbell, 1979). As such, a quasi-experimental study design would be the most appropriate methodological approach, whereby controls are identified before an intervention is implemented so that baseline measures can be taken.

A clear target outcome must be defined, followed by a clear model of how the intervention will prevent the injury of interest. As previously mentioned, chronic outcomes (i.e. MSD) may be difficult to measure, suggesting the use of intermediate outcomes – measurable events along the casual pathway from the intervention to the injury outcome (ex. worker's knowledge, attitudes, and behaviours) (Verbeek et al., 2004). Furthermore, it would be beneficial to identify critical variables (i.e. vibration dosage values and knowledge level) used in similar studies so that data can be aggregated and easily compared.

The four elements of intervention content, implementation context, implementation process, and target outcomes need to be considered when introducing an OHS intervention to the workplace. Not only will it increase the chances of success but it may also provide insight into why an intervention failed, whether it is a theory failure (the intervention was implemented properly but did not produce the intended effect) or a programme failure (the intervention was not implemented as planned) (Kristensen, 2005).

2.7 Thesis Objectives

The purpose of this research is two-fold. Firstly, to determine the validity of the WBVpod against a gold-standard tri-axial accelerometer and data logger system for WBV measurements. Secondly, to determine if the use of the WBVpod when combined with three vibration education sessions will affect perceived knowledge of health effects and control strategies. Feedback on the application from the participants will also be collected.

The first objective will be accomplished via a laboratory and field study. The objective of the laboratory phase is to validate the WBVpod against the gold-standard method under simultaneous exposure to WBV profiles, generated by a vibration simulator. The generated profiles will be derived from previous field measures of mobile equipment in the forestry, mining, and construction sectors. The profiles of the vibration exposures will involve set amplitudes in both the translational (x, y, z axes) and rotational (roll, pitch, yaw) planes of motion. In addition, random sinusoidal vibration exposures will also be tested. Resultant data from the WBVpod and gold standard measurement system will be compared. The performance of the WBVpod will be further evaluated during the field phase of the study. A selected number of trials will be conducted during the operation of a load-haul-dump (LHD) vehicle used in underground mining. Again, vibration outputs measured with the WBVpod will be compared to the vibration measurements obtained with the gold standard equipment.

The second objective will be pilot testing the WBVpod as a learning tool in the field with underground mobile mining equipment operators. Participating miners will be given a baseline survey to assess their perceived knowledge with regards to vibration, health effects and control strategies. All participants will be given a WBVpod in conjunction with 3 educational sessions. The educational sessions will introduce basic information on WBV, the usage of the WBVpod, and control strategies to limit WBV exposure. After a four- to six-week (production site) or 1-2 week (training site) period the participants will be asked to retake the perceived vibration knowledge survey. Pre- and post-survey scores will be compared to determine if the use of the WBVpod and educational pieces had any influence on perceived vibration knowledge.

2.8 Methods

Chapters 3 and 4 will provide more detail on the methods used for data collection and analysis.

2.9 Significance of Study

Chronic exposure to WBV is associated with an increased risk for a host of health problems, including LBP, spinal degeneration, neck problems, gastrointestinal tract problems, and fatigue. The gold standard equipment used to measure WBV exposure tends to be expensive, and requires expertise to analyze and evaluate. Thus measurements are not carried out on a routine basis, making it difficult to document and compare an individual's exposure profile against published standards (Village et al., 2012; Wolfgang et al., 2014). The WBVpod has the potential to provide an inexpensive, user-friendly, and accurate measurement tool that will allow easy comparison between exposure values and published standards. In addition, the WBVpod could help in monitoring/evaluating control strategies, and encourage individuals to take an interest in their vibration exposure. As such, the WBVpod could become a useful tool for OHS departments, small business owners, manufacturers, and workers in managing vibration-related health risks. Managing WBV-related risks begins with observing/identifying potential risk factors in the field, developing innovative interventions (i.e. control strategies) in the lab, and integrating the interventions back into the field; evaluation after integration is also important, as it will help determine the efficacy and effectiveness of the intervention. With a field-to lab-to field approach, the goal is to develop guidelines and management programs in an attempt to eliminate or reduce health risks associated with WBV exposure.

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Chapter 3

3 Evaluation of WBV iOS Application to Estimate Whole-Body Vibration Exposure

Abstract

An iOS application (WBVpod) developed to measure vibration exposure at the seat pan for mobile equipment operators was evaluated in this study. Adverse health effects from prolonged exposure to whole-body vibration (WBV) are well documented, the most common of which is low-back pain (LBP). The WBVpod was evaluated in laboratory and field trials against a gold standard device under wider frequency ranges and higher magnitudes of vibration compared to previous evaluations. Laboratory testing used a robotic platform, which replicated vibration profiles from the mining, construction, and forestry sector. The field measurements were completed using a load-haul-dump (LHD) vehicle at a mine training site. Overall, the results revealed a mean difference ranging from -0.028 – 0.002 m/s^2 for the x (fore-aft), y (lateral), and z (vertical) axes. The z-axis displayed the greatest level of agreement with an ICC of 0.97, and bias of 0.015 (+/- 0.121). The findings from this report suggest that the WBVpod can be used to measure WBV during the operation of LHD vehicles. The simplicity and affordability of the WBVpod will be an asset in routine monitoring of WBV, in addition to the evaluation of preventative strategies.

Keywords: Whole-body Vibration; iPod application; Mining

3.1 Introduction

Long-term, occupational exposure to whole-body vibration (WBV) has been strongly associated with musculoskeletal disorders, particularly lower-back pain (LBP) (Bovenzi, 2010, Bovenzi & Hulshof 1999; Teschke et al., 1999). Furthermore, WBV exposure can act as a predictor for work-related disability and subsequent disability pension retirement (Tuchsen et al., 2010). Operators of mobile equipment in the mining industry, such as load-haul dump (LHD) operators, are an at-risk group for vibration-related health problems from WBV exposure (Eger et al., 2006; Smets et al., 2010; Yoshimura et al., 2005). Although a dose-response relationship may not always be evident (Lings & Leboeuf-Yde, 2000), the fact remains that operators of mobile equipment show a higher prevalence of WBV-related health issues (Seidel & Heide, 1986), and may benefit from monitoring their WBV exposure.

Workplace surveillance systems, including those for WBV, can be an intensive undertaking due to the need for human expertise, and expensive equipment and software; this leads to infrequent recordings and monitoring (Thalheimer, 1996; Burgess-Limerick & Maslen, 2012; Village et al., 2012; Wolfgang et al., 2014). Routine monitoring of WBV can help identify areas of high vibration exposure within a workplace, which in turn could become the targets for control strategies (i.e. interventions to limit vibration exposure and ultimately lower the risk for vibration induced injuries). Furthermore, routine monitoring can help in evaluating the effectiveness, if any, of the control strategies that are implemented; this may encourage and support workers in continuing or adopting control strategies. As the capabilities of smartphones and other hand-held devices increase with the use of built-in sensors (microphones, accelerometers, cameras, proximity and light detectors) researchers and developers are finding ways to create accurate, accessible, and affordable measurement tools (Kardous & Shaw, 2014). A study by Kardous and

Shaw (2014) evaluated several sound measurement applications on a variety of smartphone devices (Apple, Samsung, HTC, and Motorola) against a gold-standard sound measurement instrument. Four applications were considered accurate and reliable enough to be used in the field assessment of occupational noise exposure. Indeed, some government and research groups have supported the use of mobile phones as part of noise pollution monitoring studies (Maisonneuve and Matthias, 2010; European Environment Agency, 2013; Kanhere, 2013). The study did find variability in the reliability between the types of handheld devices, such as the older iPhone 3GS model producing better agreement for all of the applications and noise levels tested. It was suggested that the variability could be due to differences in device hardware and microphone elements, which further highlights the importance of validating applications before they become implemented in the workplace.

To compare performance between two measurement devices, accuracy, precision, and level of agreement should be considered. Accuracy refers to the closeness of a measurement from the new device to the reference device (i.e. bias). Precision is the reproducibility or repeatability of a set of measurements. (Le Manach and Collins, 2015). A perfect device would be both accurate and precise. However, an observed difference between devices can be attributed to the new device, the reference device, or both. In some instances the percentage error is used and reports the difference between measurements from two properly calibrated devices. The more appropriate term in this case would be the level of agreement, since agreement has the intention to compare two devices both affected by error in their measurement of the true vibration magnitude. Thus intraclass correlation (ICC) values of 0.7 or greater will be considered an acceptable level of agreement (Lee et al., 1989). Since a clinically significant difference is difficult to discern when assessing vibration and health risks (i.e. low back pain), and that the

$0.1 m/s^2$ set by Wolfgang et al. (2014) could not be verified, a percent error cutoff of 20% will also be used based on the typical cut-off values for validation studies (Haeckel & Puntmann, 2001).

The WBVpod is an iOS application that uses the iPod's built-in tri-axial accelerometer to measure occupational WBV exposure (Burgess-Limerick & Westerfield, 2014). To date, several validation studies have been conducted on the WBV app. These studies included a SV111 calibrator (Svantek Sp., Warsaw, Poland), heavy and light vehicles at several surface coalmines, urban passenger buses, and a robotic vibration platform. (Wolfgang & Burgess Limerick, 2014; Wolfgang et al., 2014; McGlothlin et al., 2015; Leduc et al., 2014, Ji et al., 2014). The mean difference (m/s^2) values ranged from 0.008 - 0.036, 0.006 – 0.021, and -0.038 – 0.005 for the x, y, and z-axes, respectively. The WBVpod was able to calculate the frequency-weighted r.m.s acceleration with a 95% confidence of +/- 0.06 (Wolfgang & Burgess-Limerick, 2014) and 0.077 m/s^2 (McGlothlin et al., 2015) of the gold standard values for heavy and light vehicles at surface coalmines. There was no specific value for allowable error when comparing the vibration measuring devices, although Wolfgang & Burgess-Limerick (2014) deemed the vibration amplitudes recorded by the iPod touch as sufficiently accurate if errors were less than $0.1 m/s^2$. The preliminary findings suggest that the WBV application would be acceptable for estimating occupational WBV exposure. However, further validation would help identify how the WBVpod performs when exposed to a range of 3 and 6 df (x, y, z, roll, pitch, and yaw) vibration exposure profiles with larger ranges of frequencies and higher magnitudes of acceleration. In addition, whether the use of a protective case could somehow alter the transmissibility of the vibration signal traveling from the seat pan to the iPod Touch should be evaluated since the application will be in environments where moisture, dust, and shocks are prevalent. Therefore, the study objectives were 1) to compare the level of agreement of the WBVpod with a gold-standard WBV measurement device when measuring vibration signals with a wider range of frequencies and larger magnitudes, as well as during the operation of LHD vehicles in underground hard rock mining, and 2) to determine if WBV measurement with the iPod Touch is impaired by using a protective case.

3.2 Methodology

The procedures followed in this study were approved by the Laurentian University Research Ethics Board. The level of agreement between the WBVpod and a gold standard WBV measurement device were determined by using both devices simultaneously under controlled laboratory testing with a vibration platform and in the field during operation of a load-haul-dump (LHD) mining vehicle.

3.2.1 Vibration Measurement Devices

A series 2, 10G tri-axial accelerometer (NexGen, Ergonomics, Montreal, QC, Canada) with a P3X8-2C DataLogII data-logger (Biometrics, Gwent, United Kingdom) was the gold standard WBV measurement system used in this study. WBV was also measured simultaneously with the iOS application (WBV v2.0, ByteWorks) that uses the built-in iPod Touch accelerometers. The gold standard accelerometer was placed in a rubber seat pad, in accordance with international standards for the measurement of WBV (ISO 2631-1, 1997). In some of the comparison trials the iPod was placed in a protective case (Survivor Slim, Griffin Technologies, Nashville, TN, USA) to determine if the case had an impact on the WBV measurement capabilities of the iPod. In all the evaluation trials an effort was made to align the WBVpod with the gold-standard device to ensure that the x, y, and z-axes had the same orientation (Figure 3.2), and WBV was measured simultaneously from both devices. Sampling rates were set at 89Hz and 1000Hz for the WBV application and gold-standard system, respectively.

3.2.2 Head to Head Laboratory Evaluation Procedure

3.2.2.1 Vibration Exposure Profiles

A total of eighteen unique 6 degree of freedom WBV profiles were generated with a Rotopod 3000 (Mikrolar Inc., Hampton, NH, USA) with trial duration ranging from 1 - 13 minutes. The profiles were selected from a group of 70 of the most common combinations of vibration exposures (Dickey et al., 2010) from field data collected from three different industry sectors: mining, forestry, and construction (Cation et al., 2008; Eger et al., 2008; Grenier et al., 2009). Trials 17 and 18 consisted of several 20-second profiles (also from the group of 70) strung together in groups of five and twenty-five to create profiles of longer duration. The unweighted dominant frequency of these profiles ranged from 0.8 – 16 Hz, and the unweighted r.m.s ranged from 0.2 – 3.5 m/s^2. Also, trials 6,7,13, and 14 consisted of random 3 degree of freedom (linear accelerations only) broadband profiles (0.5-20 Hz, with unweighted r.m.s amplitudes of 0.55 and 1.0 m/s^2) (Table 3.2). The six digits that represent a single profile correspond to the three orthogonal axes: x, y, z, and the rotation around the orthogonal axes: roll (x), pitch (y), and yaw (z). The digits, 1-3, in the profile column of Table 3.1 represent the tertile of vibration magnitudes collected in the field (Figure 3.1). Each translational and rotational axes are represented by a tertile, which is the distribution of vibration magnitudes into three parts. For example, the first digit of a profile represents the x-axis; therefore a number one would mean that the magnitude of vibration in the x-axis would be in the lower third of the tertile when considering the range of magnitudes collected in the field, which corresponds to a low magnitude. Conversely, a number three would represent a magnitude of vibration in the x-axis found in the upper third of the tertile, which corresponds to a high magnitude of vibration. Thus the numbers 1-3 do not represent a specific magnitude, but instead represent a distribution of vibration magnitudes that were collected in the mining, forestry, and construction sector. This approach provided a diverse range of profiles to evaluate the WBV measurement capabilities of the WBVpod against the measures obtained with the gold-standard device. Trials 1 to 16 (Table 3.2) had duration times of less than 90 seconds, whereas trials 17 and 18 were a combination of the either 5 or 25 6df profiles similar to the profiles of trials 1 to 16 to yield trials of longer duration.

Table 3.1 Six degree of freedom profiles with description of magnitudes of low (l), moderate (m), and high (h) magnitude acceleration levels based on previous measures of field measures of WBV (Cation et al., 2008; Eger et al., 2008; Grenier et al., 2009).

Profile	a_x (m/s^2)	a_y (m/s^2)	a_z (m/s^2)	Roll (rad/s^2)	Pitch (rad/s^2)	Yaw (rad/s^2)
333322	h	h	h	h	m	m
111113	l	l	l	l	l	l
223212	m	m	h	m	l	m
112113	l	l	m	l	l	h
211232	m	l	l	m	h	m
323333	h	m	h	h	h	h
333333	h	h	h	h	h	h

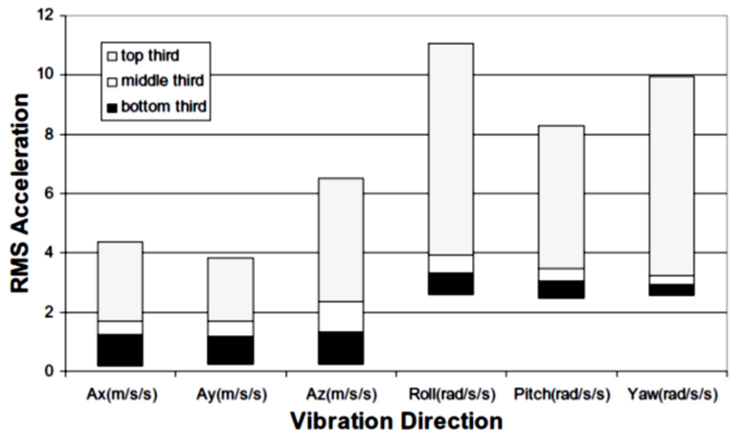

Figure 3.1 Magnitude of the unweighted vibration (r.m.s.) from the 20-second exposures of the field data for each vibration direction. The range as well as the division into the top, middle and bottom thirds are shown. Adapted from Dickey, et al., 2010. The systematic approach to simulating occupational WBV using a 6df robot.

3.2.2.2 Vibration Simulator and Set-up of the Vibration Measurement Devices

A KAB 525 industrial seat (KAB Seating Ltd.) was installed on the 6df Rotopod for all the head to head comparison trials. The seat pad of the gold standard measurement system was secured to the industrial seat with duct tape. The x, y, and z-axis of the iPod (with and without a protective case) was aligned with the gold standard device and also secured to the industrial seat with duct tape (Figure 3.2). All trials that investigated the effect of using a protective case were conducted in the laboratory setting. Seven unique profiles were measured twice, for a total of 14 trials. Trials 1 to 7 and trials 8 -14 used the same vibration profiles, however, trials 1-7 were measured without a protective case, whereas trials 8 to 14 were measured with a protective case (Table 3.2). One healthy male (73kg; 184 cm) sat on the measurement devices that were secured to the industrial seat for all the laboratory trials.

3.2.3 Head to Head Field Vibration Comparison Procedure

Head-to-head comparisons of the WBVpod and gold standard WBV measurement devices were conducted in the field to determine the suitability of the WBVpod for WBV measurements in the field.

3.2.3.1 WBV Exposure and Participants

WBV exposure was measured during the operation of two LHD vehicles, both having a haulage capacity of 2.5 yard, at training mine site in Onaping Falls, Ontario. Six volunteer trainees (n=6) with a mean age of 28 (SD 6.7) years took part in the study. Their mean height was 179 (SD 3.2) cm and mean weight of 85 (SD 14) kg .The participants drove the LHD vehicles over the same training route, which consisted of driving the LHD to a designated muck pile within the mine to load the bucket, exiting the mine with a loaded bucket, and finally dumping the muck in a designated location and driving with an empty bucket back to the muck pile. A total of 6 comparison trials were completed during the operation of an LHD vehicle (Trials 19-24 in Table 3.2). For each of the six LHD trials the route was consecutively repeated 1-2 times per trainee, to yield an average trial duration of 25 minutes.

3.2.3.2 Set-up of the Vibration Measurement Devices

In accordance with ISO 2631-1 (1997) a rubber seat pad was made to house the tri-axial accelerometer of the gold standard device and the iPod (in a protective case) (Figure 3.3). A polyurethane rubber material (Poly 74-Series, Polytek Development Corp., Easton, PA, US) was used to make the seat pad (diameter = 19cm, thickness = 1.5cm). The seat pad containing the gold standard tri-axial accelerometer and iPod was secured to the seat pan of the 2.5-yard LHD with duct tape. The research assistant ensured that both devices were aligned and orientated as required in the ISO 2631-1, with z-axis measuring vertical vibration, x-axis measuring front-to-back vibration, and the y-axis measuring side-to-side vibration. At the beginning of each participant's training run a new trial was created for a total of 6 comparison trials.

Figure 3.2 Setup of WBVpod and gold standard device on seatpan for laboratory trials with the 6 df robotic platform.

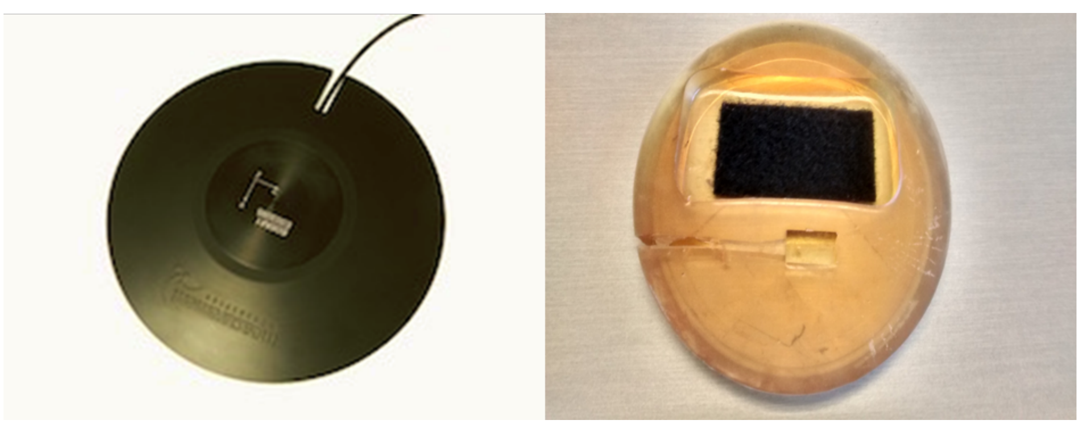

Figure 3.3 SAE seat pad used with series-2 tri-axial accelerometer (image left); custom-made seat pad to accommodate series-2 and WBVpod devices (image right).

3.2.4 Data Analysis

3.2.4.1 Frequency-weighted r.m.s Acceleration

WBV measurement outputs collected with the WBVpod and gold standard device, in the laboratory and in the field, were compared. The frequency-weighted r.m.s acceleration (aw_x, aw_y, aw_z) for each device was calculated according to Equation (2) where a_w is the frequency-weighted r.m.s acceleration, T is the measurement duration, and $a_w(t)$ is the frequency-weighted acceleration at time t.

$$a_{w}=\left[\frac{1}{T\int_0^T a_w^2(t)dt}\right]^{1/2} \text{ Units are m/s}^2 \qquad (2)$$

When calculating the frequency-weighted r.m.s acceleration, the first and last 10 seconds of the measurement signals are removed to account for any self-generated vibration produced from getting on and off the seat.

WBV data from the gold standard device were transferred to a PC for further analysis. The raw acceleration files from the data-logger were analyzed using Vibration Analysis ToolSet V3 software (VATS, NexGen Ergonomics, Montreal, QC, Canada). Filters remove unwanted elements of a vibration signal, such as frequencies beyond a certain range, based on cut-off values. Thus a high-pass filter removes low-frequency elements; low-pass filter removes high-frequency elements (Mansfield, 2004). The signals were high-pass filtered at 0.5 Hz and low-pass filtered at 500 Hz using a Butterworth filter analyzed under the comfort application, meaning that the filter weighting factors for all axes were k = 1.0. The developers of the WBVpod used the k=1.0 factor; therefore, the same factor was used when processing WBV data with the gold standard device to allow for direct comparison to the values calculated by the

WBVpod. The r.m.s values from the iPod signals were emailed to a laptop computer for further analysis.

3.2.4.2 Health Guidance Caution Zone

The ISO-2631-1 (1997) Health Guidance Caution Zone (HGCZ) defines two boundary levels which coincide with the zones or level of risk associated with a particular magnitude of vibration exposure that has been normalized to an 8-hr shift (A(8) or VDV(8)). The lower and upper boundary values are 0.47 and 0.93 m/s^2, respectively. The 8-h HGCZ assists in interpreting the daily dosage values of the worst axis of either the aRMS or VDV value and states that, “For exposure below the zone, health effects have not been clearly documented and/or objectively observed; in the zone, caution with respect to potential health risks is indicated and above the zone health risks are likely.”

The WBV application uses lower and upper boundary values of 0.47 – 0.93 m/s^2. Furthermore, an operator’s exposure values are plotted against a color-coded graph that is divided into green (low health risk), yellow (moderate health risk), and red (high health risk) zones as defined by the aforementioned boundary values.

3.2.4.3 Analysis

There is no clear criterion for an acceptable cut-off for allowable error or percent difference for WBV measurement devices. However, a study by Wolfgang & Burgess-Limerick (2014) that evaluated the WBVpod deemed that errors less than 0.1 m/s^2 were sufficient. Furthermore, Haeckel & Puntmann (2001) reported that the allowable error when validating an instrument can range from 2-20%. Thus the criteria for agreement between the WBVpod and gold standard were based on percent errors of less than 20% and WBVpod measures that are within 0.1 m/s^2 of the gold standard. The levels of agreement between the two devices were determined using an intraclass correlation coefficient ($ICC_{2,1}$) and limits of agreement for each axes. The criteria for good reliability for between methods of measurement are 0.7 to 0.97 (VanHees et al., 2009) Differences between the paired frequency-weighted r.m.s accelerations were also examined using a Bland-Altman plot test, which plots the difference between the two devices against the mean value of the two measurements for each trial. The ICC was done using SPSS software, version 20.0 (IBM SPSS, 2011), whereas the Bland-Altman was completed using Microsoft Excel (Microsoft Corp., Redmond, WA, USA).

Measurement periods ranging from 80 seconds to 37 minutes were completed to observe if variation in trial length resulted in increased error (difference – units: m/s^2) between the two devices.

3.3 Results

3.3.1 Mean Difference of WBVpod

Twenty-four WBV measurements trials were collected simultaneously from the WBVpod and gold standard devices (Table 3.2). The frequency-weighted r.m.s. (*a*r.m.s) acceleration for each device was measured at the operator/seat interface for both laboratory (industrial seat mounted on a robotic platform) and field trials (LHD vehicles during trainee mucking tasks). The difference between the *frequency-weighted* r.m.s (aw_x; aw_y; aw_z) values for the iPod Touch and gold standard are reported in the difference column for each axis. In addition to the differentiation between field and laboratory trials, differences in measurement duration and use of a protective case were also examined. Overall, the z-axis displayed the greatest level of agreement (Table 3.3), with the use of a protective case having no significant effect (Figure 3.4). Lastly, the WBVpod performed better field measurements (Figure 3.6).

The mean difference, standard deviation, and limits of agreement for the frequency-weighted r.m.s. acceleration values are summarized in Table 3.3. The z-axis had the greatest level of agreement and the least bias (ICC = 0.97, bias = 0.015 m/s^2) (Figure 3.4). However, it demonstrated wider limits of agreement, with 95% of the measurements falling within the range of 0.136 m/s^2 below and 0.106 m/s^2 above the gold standard measurements.

3.3.2 Protective Case

The mean difference and standard deviation (m/s^2) for the iPod without a case were -0.04 (SD 0.05) for the x-axis, 0.03 (SD 0.04) for the y-axis, and 0.03 (SD 0.03) for the z-axis. The mean difference and standard deviation (m/s^2) for the iPod with a case were -0.05 (SD 0.05) for the x-axis, 0.04 (SD 0.03) for the y-axis, and 0.04 (SD 0.04) for the z-axis (Figure 3.5). The use of a protective case had little effect on the output of the WBVpod. There was no statistically significant difference in constant error values between measures taken with and without a protective case as determined by a one-way ANOVA ($F(1,40) = .2183$, $p = .643$).

Table 3.2 Comparison of the frequency-weighted r.m.s values between the WBVpod and the gold standard for field and laboratory trials.

Trial no.	Profile	Duration (sec)	Lab/Field (L/F)	iPod Case (Yes/No)	ar.m.s (m/s^2)								
					X_{GS}	X_{iPod}	Diff.	Y_{GS}	Y_{iPod}	Diff.	Z_{GS}	Z_{iPod}	Diff.
1	333322	83	L	N	0.56	0.47	-0.09	0.45	0.45	0	0.83	0.81	-0.02
2	111113	81	L	N	0.35	0.33	-0.02	0.28	0.32	0.04	0.30	0.35	0.05
3	223212	81	L	N	0.56	0.45	-0.11	0.46	0.46	0	0.83	0.83	0.00
4	112113	83	L	N	0.23	0.26	0.03	0.26	0.29	0.03	0.19	0.19	0.00
5	211232	82	L	N	0.36	0.33	-0.03	0.58	0.68	0.10	0.31	0.32	0.01
6	R 0.55	81	L	N	0.19	0.18	-0.01	0.15	0.15	0	0.32	0.36	0.04
7	R 1.0	82	L	N	0.33	0.31	-0.02	0.27	0.28	0.01	0.56	0.64	0.08
8	333322	80	L	Y	0.47	0.37	-0.10	0.50	0.58	0.08	0.77	0.82	0.05
9	111113	82	L	Y	0.36	0.34	-0.02	0.29	0.33	0.04	0.31	0.38	0.07
10	223212	80	L	Y	0.56	0.42	-0.14	0.46	0.50	0.04	0.86	0.84	-0.02
11	112113	83	L	Y	0.26	0.27	0.01	0.26	0.29	0.03	0.18	0.19	0.01
12	211232	81	L	Y	0.35	0.29	-0.06	0.60	0.71	0.11	0.30	0.33	0.03
13	R 0.55	80	L	Y	0.20	0.17	-0.03	0.16	0.16	0.00	0.29	0.33	0.04
14	R 1.0	81	L	Y	0.34	0.32	-0.02	0.27	0.29	0.02	0.54	0.67	0.13
15	323333	61	L	Y	0.50	0.37	-0.13	0.35	0.28	-0.07	0.60	0.42	-0.18
16	333333	66	L	Y	0.56	0.52	-0.04	0.47	0.45	-0.02	0.74	0.66	-0.08
17	5 Profiles	164	L	Y	0.54	0.57	0.03	0.48	0.49	0.01	1.11	1.05	-0.06
18	25 Profiles	818	L	Y	0.57	0.64	0.07	0.50	0.53	0.03	0.99	1.00	0.01
19	Mucking- LHD	600	F	Y	0.75	0.79	0.04	0.4	0.42	0.02	0.72	0.74	0.02
20	Mucking- LHD	1020	F	Y	0.51	0.4	-0.11	0.28	0.3	0.02	0.47	0.5	0.03
21	Mucking- LHD	1825	F	Y	0.51	0.52	0.01	0.3	0.31	0.01	0.51	0.52	0.01
22	Mucking- LHD	1980	F	Y	0.42	0.45	0.03	0.28	0.29	0.01	0.48	0.5	0.02
23	Mucking- LHD	1909	F	Y	0.55	0.55	0.00	0.3	0.31	0.01	0.52	0.62	0.10
24	Mucking- LHD	1320	F	Y	0.62	0.65	0.03	0.36	0.37	0.01	0.6	0.62	0.02
Average (SD)							-0.03 (0.06)			0.02 (0.04)			0.02 (0.06)

Table 3.3 Intraclass correlation coefficient (ICC 2,1) values and limits of agreement for each axes.

Axis	ICC values (95% CI)	Mean (SD) difference between the paired measurements (m/s^2)	Lower limit of agreement (m/s^2)	Upper limit of agreement (m/s^2)	Mean (SD) percent error between the paired measurements
X	0.92* (0.83-0.97)	0.028 (0.058)	-0.086	0.143	10.8 (7.6)
Y	0.96* (0.92-0.98)	-0.022 (0.037)	-0.094	0.05	7.5 (6.3)
Z	0.97* (0.93-0.99)	-0.015 (0.062)	-0.136	0.106	9.1 (8.4)

CI confidence interval; SD deviation
*P <0.05

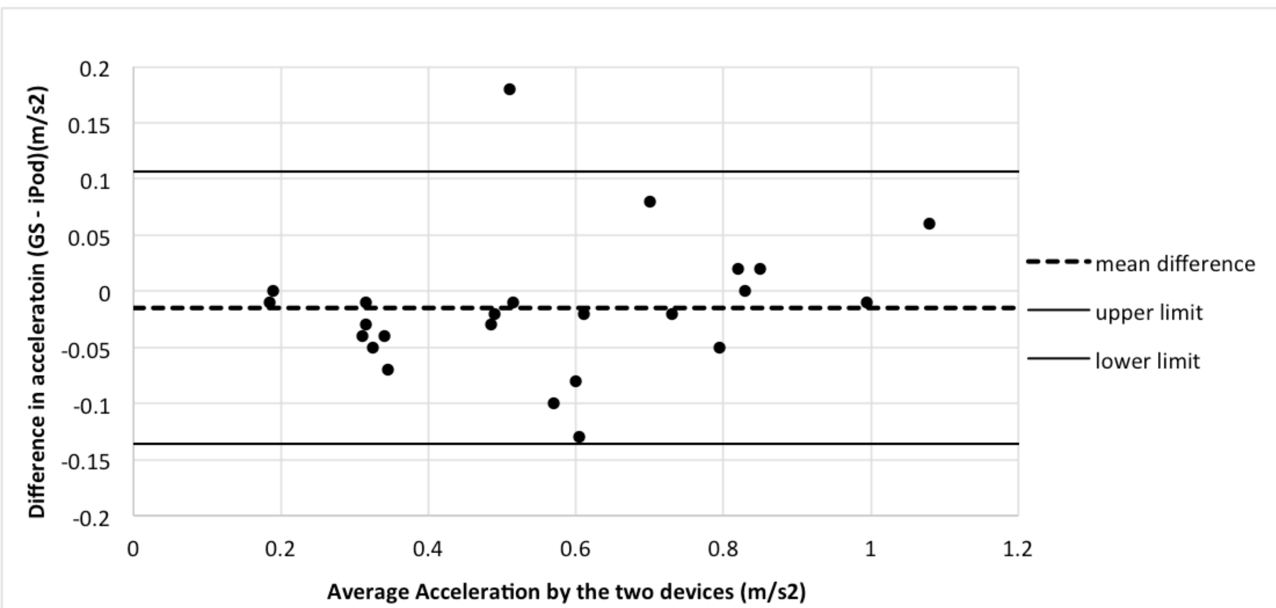

Figure 3.4 Example of Bland-Altman plot for the z-axis

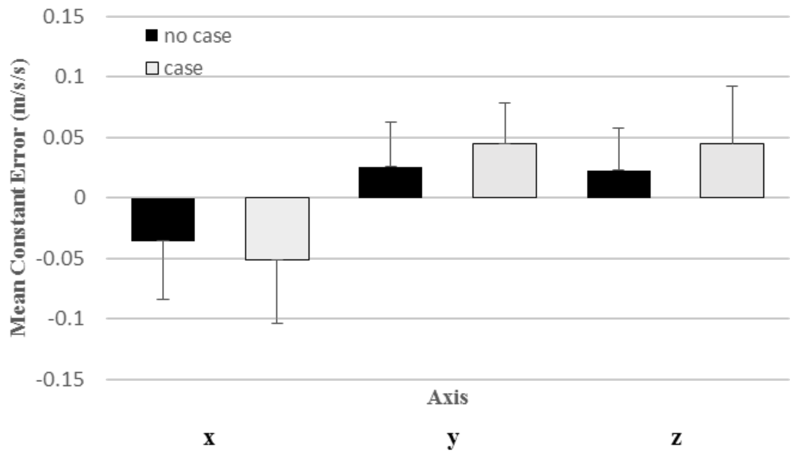

Figure 3.5 Comparison of mean difference of the r.m.s between WBVpod with and without a protective case. Bars represent 1 standard deviation.

3.3.3 Laboratory versus field measurements

The mean difference and standard deviation (m/s^2) for the laboratory trials (trials 1-18) were -0.04 (SD 0.06) for the x-axis, 0.02 (SD 0.04) for the y-axis, and 0.01 (SD 0.07) for the z-axis. Likewise, the field trials (trials 19-24) had a mean difference and standard deviation of 0.00 (SD 0.06), 0.01 (SD 0.01), and 0.03 (0.03) for the x-, y-, and z-axes, respectively (Figure 3.6).

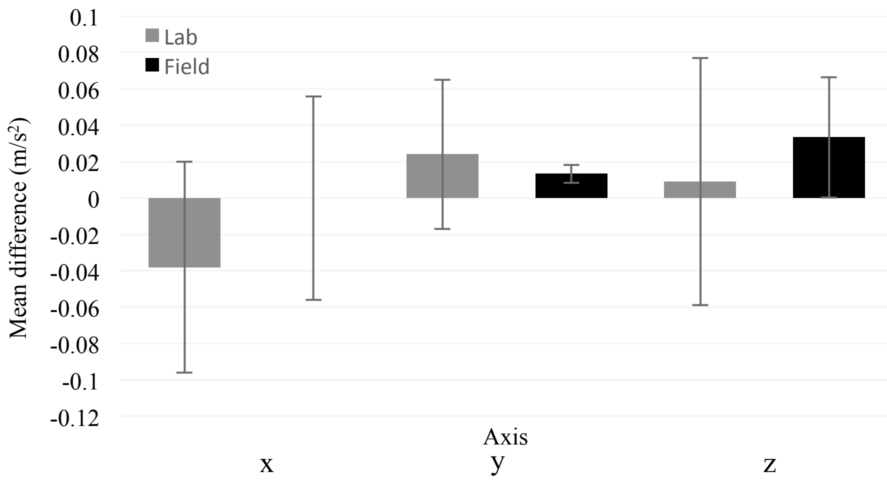

Figure 3.6 Comparison of the mean difference between laboratory and field vibration measurements for all three axes. Bars represent +/- 1 standard deviation.

3.3.4 Dominant Frequency

The dominant frequencies for the laboratory trials ranged from 1.6-16 Hz. The largest difference between the two devices (m/s^2) at a specific dominant frequency were -0.14 (dominant frequency = 1.6 Hz) for the x-axis, 0.11 (dominant frequency = 1.6 Hz) for the y-axis, and -0.18 (dominant frequency = 4 Hz) for the z-axis. There is no apparent trend between the constant error and the range of dominant frequencies experienced during the laboratory trials (Figure 3.7). Likewise, the dominant frequencies for the six field trials were all similar: 1.6, 1.6 and 4-5 Hz for the x-, y-, and z-axes, respectively. Similarly, no trends between the constant error and the range of dominant frequencies in the field were apparent.

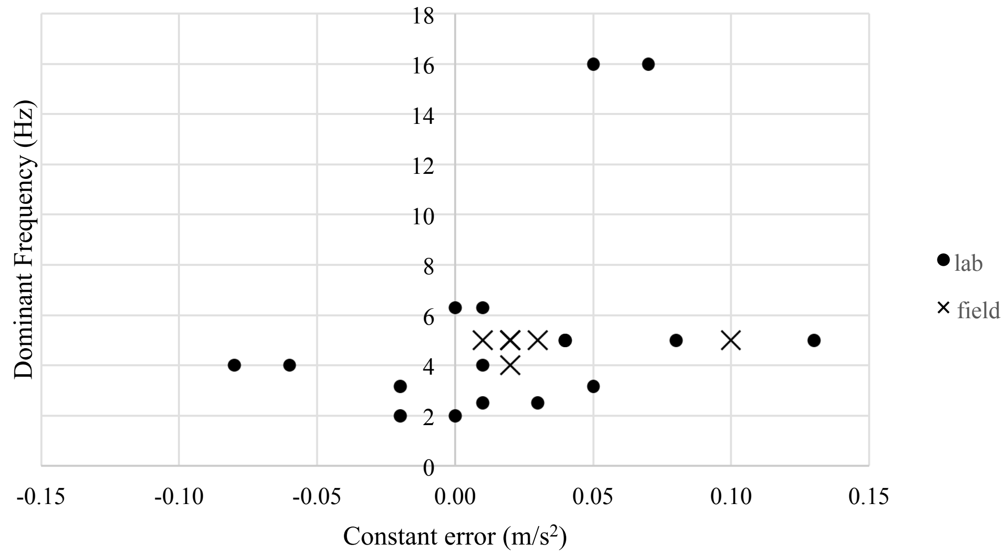

Figure 3.7 The effect of dominant frequency on the constant error (m/s^2) of the WBVpod for the z-axis

3.4 Discussion

3.4.1 Level of Agreement of the WBVpod

The primary objective of this study was to evaluate the level of agreement between the WBVpod and the gold standard WBV measurement system. Our results are in line with previous studies, which reported WBV measured with the WBVpod, were similar to those collected via gold-standard devices (McGlothlin et al., 2015; Wolfgang et al., 2014; Ji et al., 2013). Previous studies have indicated that the WBVpod is able to estimate the frequency-weighted r.m.s with a 95% confidence of +/- 0.09 m/s^2 or better, with the level of agreement being the greatest in the vertical direction: 95% confidence of +/- 0.06 (Wolfgang et al., 2014) and 0.077 m/s^2 (McGlothlin et al., 2015).

In this study the greatest standard error occurred in the x-axis (Table 3.3.), which was also noted by Wolfgang et al., 2014. While the current study only had three profiles with a dominant x-axis for both devices these inaccuracies could be problematic in real-world applications. The lack of agreement may lead to misclassification of health risks when the dominant exposure is in the x-axis, as occurs in vehicles such as bulldozers, excavators, crawler loaders, and compactors (Burgess-Limerick & Maslen, 2012; Cann et al., 2003).

The WBVpod was designed to act as a screening tool that will alert workers/employers of low and high-risk tasks within the workplace. Although the WBVpod is within reasonable performance to the gold standard, a single measurement trial would not be a sufficient representation of the vibration exposure for a task. Instead, multiple measurements should be taken to develop a baseline to obtain a better representation of the actual health risk of a particular task. Once a distinction between high- and low-risk tasks is evident, employers and workers can consult with OHS specialists to confirm their findings with the gold-standard measurements, and concentrate their preventative efforts on the high-risk tasks.

3.4.2 Protective Case

The secondary objective of this study was to determine if the use of a protective case with the WBVpod would have a significant impact on WBV measurement. Using a protective case - composed of a silicone jacket and polycarbonate inner shell - had no significant effect on the instruments capabilities (ANOVA ($F(1,40) = .2183$, $p = .643$). This is reassuring since a protective case is needed to protect the WBVpod when used for field applications where moisture, dust, and shock/impact (dropping the iPod Touch) are prevalent.

3.4.3 Laboratory versus Field Measurements

The laboratory provided a highly controlled environment, reducing the effects of confounding variables. While a controlled ('artificial') environment is not reflective of the field (natural environment), it does allow for a direct comparison of conditions. The robotic platform allowed the research team to directly compare the output values of the WBVpod and gold standard under identical vibration exposure conditions. Furthermore, the performance of the WBVpod could be tested under a range of vibration amplitudes and frequencies (i.e. extremes) that the robotic platform was able to replicate.

Field-testing was then carried out to see how the application would perform. In previous studies field trials were completed for urban buses (Leduc et al., 2014), heavy vehicles including haul trucks, dozers, graders, and excavator at a surface coal mine (Wolfgang et al., 2014; McGlothlin et al., 2015), and light vehicles (Wolfgang & Burgess-Limerick, 2014; McGlothlin et al., 2015). This study evaluated the performance of the WBVpod during underground operation of a LHD vehicle. Previous field measures of LHD vehicles suggest that vibration exposure would range from moderate to high risk; 0.52 – 2.25 m/s^2 (Eger et al., 2006; Eger et al., 2011; Eger et al., 2013; Village et al., 1989). The findings were similar in this study, with all LHD exposures falling within the moderate health risk level. Overall, the WBVpod appeared to perform better during field trials compared to the laboratory trials (Figure 3.6). The better performance in the field trials could be because the field trials had vibration profiles with lower magnitudes of vibration and narrower frequencies ranges compared to the laboratory trials. The mean differences for the x- and y-axes were lesser in the field trials; however, the mean difference for the z-axis did not follow the same trend. Conversely, the standard deviations were lesser for the y- and z-axes in the field trials. Previous field studies evaluating the WBVpod noted the x-axis as being the least accurate (Wolfgang et al., 2014), as did the current study. Lastly, our confidence limit values of +/- 0.08 m/s^2 are more in-line with the +/- 0.06 (Wolfgang & Burgess-Limerick, 2014) and 0.077 m/s^2 (McGlothlin et al., 2015) confidence limits values calculated from the field validation trials.

The reasons behind the differences in error (Figure 3.8) and agreement are uncertain. While it appears that the duration of the trial many play a role in the variability (average laboratory trial duration: 78.8s; average field trial duration: 1204.5s), it is morel likely the content of the vibration profile. It so happens that the laboratory trials, while shorter in duration, contain higher magnitudes of acceleration and wider ranges of frequencies than the field trials (longer duration). Thus the limits of the WBVpod were more likely to be reached during the laboratory trials than the field trials due to the aforementioned differences in the content of the vibration profiles. The source of variability is most likely due to the differences in sampling rate between the WBVpod and gold standard device (see section 3.4.3.2).

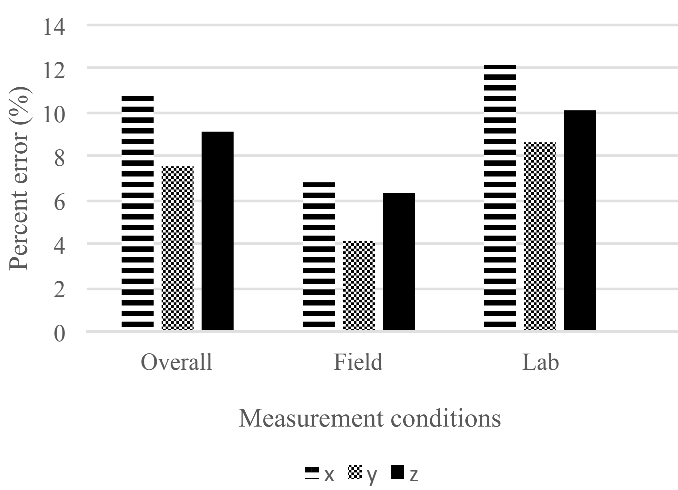

Figure 3.8 Difference in percent error when comparing frequency-weighted r.m.s values between the WBVpod and the gold standard

3.4.3.1 Types of Vibration

The WBVpod was tested under two types of vibration: random, broadband vibration, and 'real-world' vibration. The former was only experienced under laboratory conditions. The broadband vibration had random 3 degrees of freedom (linear accelerations only) frequencies between 0.5-20 Hz, with unweighted r.m.s amplitudes of 0.55 and 1.0 m/s^2. Conversely, the 'real-world' profiles experienced in the lab and field consisted of random six degree of freedom (linear and rotational accelerations) vibration. Based on the values in Table 3.2 there are no appreciable differences between the mean differences of the random 3df broadband (R 0.55 and 1.0) and 6df random vibration types in the laboratory trials.

3.4.3.2 Sampling Rate and Frequency Content

Measuring a vibration signal requires a data-acquisition system with an adequate sample rate. Inadequate sampling rates produce 'aliased' signals, whereby the sampled signal indicates a lower-frequency signal than the original, higher-frequency signal. The greater the difference between sample rate and frequency content, the less the sampled signal will resemble the original signal. To avoid the aliasing effect, the sampling rate should be at least twice the highest frequency to be reproduced, also known as the Nyquist Theorem (Whitaker, 1915; Shannon, 1949; Nyquist, 1928). It was hypothesized that the WBVpod would underestimate vibration signals with high frequency components, given the low sampling rate of the iPod (89 Hz) in comparison to the gold standard (1000 Hz) (McGlothlin et al., 2015; Wolfgang et al., 2014). The higher the sampling rate, the more likely the sampled signal will be representative of the true signal. Thus, if the sample rate is too low the original signal will not be accurately measured (Mansfield, 2005) (Figure 3.9).

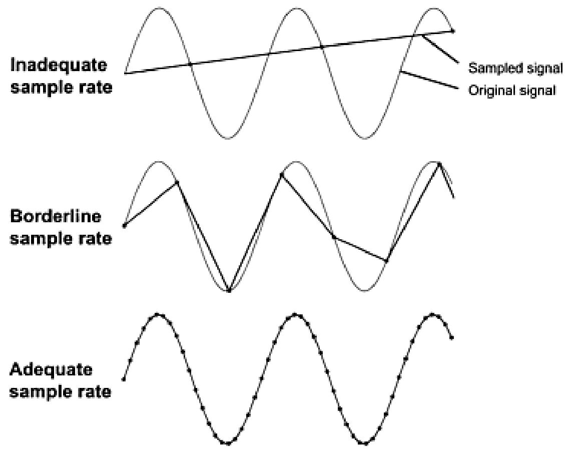

Figure 3.9 Effect of sampling rate to adequately measure a vibration signal. Reprinted from Human Response to Vibration (p.103), by N.J. Mansfield, 2005, Boca Raton, FL: CRC Press. Copyright 2005.

Based on the WBV measurements conducted in this study there was no apparent relationship between the dominant frequency and mean difference (Figure 3.7). The dominant frequency is the peak (highest point) on a frequency domain graph (i.e. spectral plot). The spectral plot will show if there is energy present at given frequency (Mansfield, 2004). Likewise, the resonance frequency is the point at which a structure (ex. organ/tissue) experiences maximal displacement; therefore, increasing the risk of injury (ex. low back pain/sciatica) by placing increased loads on the structure (Bovenzi 1999, 2004; Kuijer et al., 2015; Pope et al., 1989). For example, if the dominant frequency coincides with the resonance frequency of an operator's spine (4-10 Hz) (Hagena et al.1985; Panjabi et al., 1986; Pope and Novotny, 1993; Kitazaki & Griffin, 1997;), an operator's spine would experience increased loads, thereby increasing their risk for low back pain. Again, low back pain is associated with chronic exposure to WBV. The vibration frequencies experienced in the lab and at the seat pan for the current study (1.6 -16 Hz) coincide with the dominant frequencies measured in other studies LHD: 1.0 – 3.15 Hz (Eger et al. 2011) and 1.6 – 3.15Hz (Village et al., 1989). The lower dominant frequencies relate to an operating LHD, compared to an idling LHD that would have higher dominant frequencies (Village et al., 1989). Although the sample rate of the WBVpod is low in comparison to the sample rate of the gold standard, the 89Hz sampling rate of the WBVpod is still more than twice the rate of the WBV exposure frequencies (1-20 Hz) suggested by ISO 2631-1 to be linked with adverse health effects (ISO 2631-1, Thalheimer, 1996; Mansfield & Griffin, 2002). Furthermore the dominant WBV exposure frequencies associated with the operation of mobile equipment are 0.8 – 8.0 Hz (Smets et al., 2010, Jack et al., 2010, Cation et al., 2008, Grenier et al., 2010; Eger et al., 2011), including 1.0 – 5.0 Hz for LHD vehicle exposures measured in the current study.

Based on the levels of agreement in both the laboratory and field settings, along with the lower mean difference and variability values observed in the field trials, the WBVpod would be a suitable WBV measurement tool for use in trials in LHD operations in underground mining. There was no apparent trend for a dominant frequency at which the WBVpod performed poorly on (Figure 3.7). However, in terms of vibration magnitude the WBVpod seemed to perform poorly (a difference greater than 0.1 m/s^2) on profiles with higher magnitudes of vibration (laboratory trials) compared to the lower vibration magnitudes in the field (Figure 3.6). These findings are consistent with Wolfgang et al., (2014) who noted that the WBVpod was increasingly likely to underestimate the true vibration as the vibration amplitude increased. However, this trend disappears when longer duration trials were created by combining multiple low, moderate, and high magnitude profiles. Future testing could evaluate how the WBVpod performs when exposed to exclusively high magnitude profiles (ex. profile 333322 or 323333 continuously repeated) for varying lengths of time. It is suggested that vibration measurements taken with the WBVpod should be of longer duration (greater than the average duration of the single profiles), especially when dealing with high amplitudes of vibration (high amplitude denoted by a ‘3’ in the 6df profile: 333322).

3.4.4 Practicalities in Occupational Vibration Measurement

Occupational measurements of WBV can be performed by direct measurement with a tri-axial accelerometer and data-logger, or by an indirect method through trained observers and self-reports (Burstyn & Teschke, 1999; Chen et al., 2003; Village et al., 2009). The former, while accurate, requires technical expertise and is expensive: Teschke et al., (2009) reported a cost of $1020 for direct vibration measurement per shift. The latter, while less expensive, lacks accuracy and is subject to recall bias (Village et al., 2012). Likewise, should an employer choose to purchase the equipment (DataLOG, series-2 tri-axial accelerometer, and seat pad) and software necessary for WBV measurement, it could cost approximately $10,500 USD (NexGen). The cost of a 16 GB iPod Touch (Apple Inc., Cupertino, CA) is lower than its gold-standard counterpart, retailing for $249 USD. In addition to being more affordable, the WBVpod has been previously reported to be an accurate and user-friendly vibration measurement tool that could be used across many occupations and industries (McGlothlin et al., 2015).

The practicality of the WBVpod lends itself to its low cost, simplicity in setting up, and its intuitive feedback through a colour-coded HGCZ graph. The results calculated by the application provide an intuitive way to characterize the level of health risk associated with WBV exposure by using a colour co-ordinated graph of the HGCZ, as well as displaying the operator's time to reach the HGCZ. Essentially, an individual with a limited background in WBV assessment can glance at their results and quickly determine if they are in the green, yellow, or red zone and/or how long they would have to be exposed to the current vibration magnitude to reach the HGCZ. Secondly, with smartphones and hand-held devices penetrating 68% of the Canadian population, (CATALYST, Toronto, ON, Canada), the public are becoming increasingly familiar with handheld technology. This increased familiarity could make it easier for the general population to access and incorporate these smartphone-monitoring applications into their daily lives. Future research is needed to determine the practicality of using the WBVpod as part of a WBV monitoring and management program based on feedback from the workers.

3.4.5 Limitations

In the head-to-head comparisons conducted in the laboratory and field the two devices were aligned by the same research assistant in the same manner in an effort to minimize misalignment as a source of error and the devices were secured to the seat pan using duct tape to ensure that the devices did not shift during the trial. However, it is possible that there was some error in alignment of the axes. Especially when an individual sits on a cushioned seat to which the devices are attached, because the surface is not rigid the devices will tend to shift and introduce some misalignment. This misalignment may create greater error on any of the individual axes. By comparing the vector sum of the frequency-weighted r.m.s for all 3 axes between devices, it is possible to see if the vector sum contains a higher level of error than any one axis. Future practices could attempt to control for alignment by securing both devices side-by-side to a rigid surface, zero the devices, and evaluate against a controlled sinusoidal vibration. Any differences between the devices can then be offset. However, as previously mentioned workers are not sitting on rigid surfaces, thus the comparison of the devices on a cushioned seat would provide a more practical representation of using the devices in the workplace.

Conclusion

Overall, the outputs from the WBVpod were comparable to the outputs of the gold standard measurement device. Head-to-head comparison of the two devices in both the laboratory and field resulted in mean differences (m/s^2) of -0.028, 0.022, and 0.015 m/s^2 for the x, y, and z-axes.

The most common and severe health effects associated with WBV exposure are musculoskeletal disorders, most notably low back pain and sciatica (Bovenzi, 2005; Thalheimer, 1996). While vibration exposure is recognized in some European countries as a compensable occupational risk, there remains difficulty in adequately measuring an operator's daily vibration exposure (Johanning, 2015). This creates barriers for implementing any form of health surveillance, whose primary goals are to identify and protect workers at increased risk, as well as monitoring the effectiveness of control strategies. Control strategies themselves are designed to target factors that influence WBV exposure, and may include such practices as reduced driving speeds, road maintenance, and operating techniques (Eger et al., 2011). If successful the WBVpod could allow for regular monitoring and measurement of an operator's daily vibration exposure, which in turn may aid in further developing models linking the amount of exposure to an outcome (e.g. low back pain or sciatica). In addition, providing workers with easy access to WBV measurements may help increase awareness of associated health risks and encourage the undertaking of control strategies to mitigate WBV exposure. Future research is needed to determine the practicality of using the WBVpod as part of a vibration monitoring and management program based on feedback from the workers.

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Chapter 4

4 Evaluation of an Intervention on Perceived Whole-Body Vibration Knowledge in Mobile Equipment Operators in Underground Mining

Abstract

Long-term exposure to whole-body vibration (WBV) has been associated with an increased risk for a variety of health effects, most notably low back pain (LBP). A WBV intervention was developed using a combination of an iOS application (WBVpod) for WBV measurement and a series of educational pieces on WBV in the context of adverse health effects, methods of measurement, and control strategies. The intervention was evaluated using a within-subject pre-post-test design. A composite WBV knowledge level score was obtained from the median question response on a Likert (KL1-5) survey from several operators of mobile equipment, followed by an intervention consisting of the WBVpod and three educational sessions (up to 5-6 weeks), and post intervention assessment using the same survey from baseline. The results revealed an increase in knowledge level after the use of the WBVpod and supplementary sessions. The WBVpod received positive reviews in terms of its simplicity and providing operators the ability to assess their own vibration exposure. However, the majority of operators noted discomfort when sitting on the custom made seat pad designed to house the WBVpod for an extended period of time (i.e. a 6-8 hour work shift). The logic behind improved WBV knowledge is that the enhanced knowledge and ability to measure WBV easily will encourage workers/employers to adopt practices to reduce vibration exposure in the workplace and ultimately reduce the risk for adverse health effects, including LBP.

Keywords: Whole-body Vibration; Knowledge Transfer; Mining

4.1 Introduction

The purpose of occupational health and safety (OHS) interventions are to reduce or eliminate workers' exposures to a workplace hazard, such as whole-body vibration (WBV). It has been reported that 4-7% of the European and North American workforce are exposed daily to harmful levels WBV (Bovenzi, 1996). The health effects associated with chronic WBV exposure can include headaches, nausea, gastrointestinal discomfort, reproductive issues, and fatigue (Scutter et al., 1997; Seidel, 1993; Wikstrom et al., 1994; Seidel & Heide, 1986). A review by Seidel and Heide (1986) provides a glimpse at the wide range of occupations reporting WBV exposure, including truck drivers, tractor drivers, crane operators, and pilots. The health effects most strongly associated with chronic exposure include low back pain (LBP) and sciatica (Burström et al., 2015). Furthermore, cumulative exposure to WBV can be a precursor of disability and lost-time for work (Boshuizen et al, 1990). It is for these reasons that elimination or reduction of WBV in the workplace is important.

Reducing or eliminating exposure to WBV may be accomplished through three types of interventions: engineering, administrative, and behavioural. Engineering interventions include improvements to seating and cab suspension, whereas administrative interventions focus on procedures and policies, such as job rotation, or work scheduling that reduces a worker's exposure duration to WBV; personal interventions focus on a worker's behaviour, education and training. While engineering interventions are preferable as it takes the onus off of the worker, neither type of intervention may be sufficient on its own, which is why many OHS interventions employ a multifactorial intervention approach (Tiemessen et al., 2007). However, given the time and resources available, some studies may only have the option of including one type of intervention. While the ultimate goal of an OHS intervention is to reduce the risk of workplace injury by limiting a worker's exposure to a hazard, the effectiveness of the intervention may lack evidence due to the design of the intervention. Intervention studies that employ a randomized-controlled trial are considered an ideal design, because the observable effect of the intervention would be distinguishable from all other confounding variables that could influence the outcome of interest (i.e. WBV exposure and LBP). However, given that LBP is a chronic condition (i.e. the condition develops over a long period of time), randomization would require large samples sizes and long follow-up periods to obtain enough statistical power (i.e. in this example the likelihood to detect a difference in a sample/population that actually exists (Gordis, 2009)). A more practical study design for OHS interventions includes a quasi-experimental design with intermediate outcomes. A quasi-experimental design occurs when the controls are identified before the intervention is delivered, thereby allowing baseline measures to still be measured (Goldenhar & Schulte, 1996; Cook & Campbell, 1979). Likewise, intermediate outcomes are measurable events along the casual pathway from the intervention to the injury outcome. In contrast to chronic outcomes (i.e. LBP), intermediate outcomes may include a measure of a worker's knowledge, attitude, or behaviour regarding the exposure of interest (i.e. WBV).

Although a quasi-experimental design is not the gold standard of study designs, it can still be a high-quality intervention. The criteria for high-quality interventions are clear objectives, methods, and outcome measures. Therefore, if there is a change in a work-related health hazard the researchers will have a better sense of why the change has occurred (Karanika-Murray & Biron, 2015; Biron & Karanika-Murray, 2014; Goldenhar & Schulte, 1996; Zwerling et al., 1997).

The current pilot study used a pre-post design and the primary objective was to evaluate the use of the WBVpod as part of a WBV management program; an emphasis was placed on personal intervention through education and training. The WBVpod underwent laboratory validation as part of the first phase of the research project, in conjunction with several field validation trials completed by Killen, W., Chapter 3 (2015). The validation trials demonstrated that the WBV application was able to provide an accurate and affordable method of whole-body vibration assessment, and could be a valuable tool as part of WBV management program. The evaluations of the educational pieces and accompanying WBVpod were based on a whole-body vibration topics (health risks of WBV exposure, ISO-Standards, control strategies etc.) knowledge Likert-scale survey (Paschold & Sergeev, 2009) at base line and follow-up, as well as feedback on the usability of the application from a group of mobile-equipment operators (ex. haulage trucks, load-haul-dump vehicles) at a training and production mine site in northern Ontario.

4.2 Methodology

The procedures followed in this study were approved by the Laurentian University Research Ethics Board.

4.2.1 Participants

4.2.1.1 Training Mine Site

Eleven participants (n=11) were recruited from a training mine site. The training course itself consisted of a 4-week common-core program, where trainees learned how to safely operate a 2.5-yard load-haul-dump (LHD) vehicle. Participants completed a perceived WBV knowledge survey at baseline and follow-up over a 1-2 week period. In between baseline and follow-up trainees used the WBVpod during several of their training runs, and took part in informal discussion around WBV and how it relates to health effects and control strategies.

4.2.1.2 Production Mine Site

Eight participants (n=8) were recruited from an underground nickel mine in northern Ontario. Participants were experienced LHD, haulage truck, or grader operators. Given the small sample size, a within-subject pre-post study design was used, whereby the participants acted as their own controls. The participants were given an iPod Touch with the WBV application (WBVpod), and participated in three educational sessions over a period of approximately 5 weeks. The intermediate outcome of perceived WBV knowledge level was assessed at baseline and follow-up, with additional feedback on the WBVpod and supplementary training materials being provided at the conclusion of the study using a Likert-scale survey.

4.2.2 WBV Measurement

WBV exposure measurements were gathered using the WBVpod at the training mine site and production mine site for a maximum period of 1 month. The WBVpod has previously been validated against gold standard equipment for occupational WBV measurement (Killen et al., 2015; McGlothlin et al., 2015; Wolfgang et al., 2014). In addition to recording the exposure values for each group, participants were asked to include information on vehicle type (make, model, and age), and task(s) description. The general logic for the intervention is outlined in Figure 4.1, which was adapted from LaMontagne et al., 2014. Another factor that should be considered for Figure 4.1 is to include some form of action taken (simulations and/or changes in workplace policies) to support workers in applying their improved knowledge into practice. Ideally, improvements in WBV knowledge and compliance with control strategies would improve (i.e. reduce) vibration exposure, which in turn would reduce the risk for adverse health effects and improve work performance. The current study evaluated only the primary outcome of

WBV knowledge. Participants took part in a series of educational sessions based on WBV and were given the WBVpod to measure their vibration exposure for the duration of the study. The WBVpod was used to reinforce the concepts discussed in the educational sessions, as well as to gain feedback from the workers on the usability of the application in the workplace.

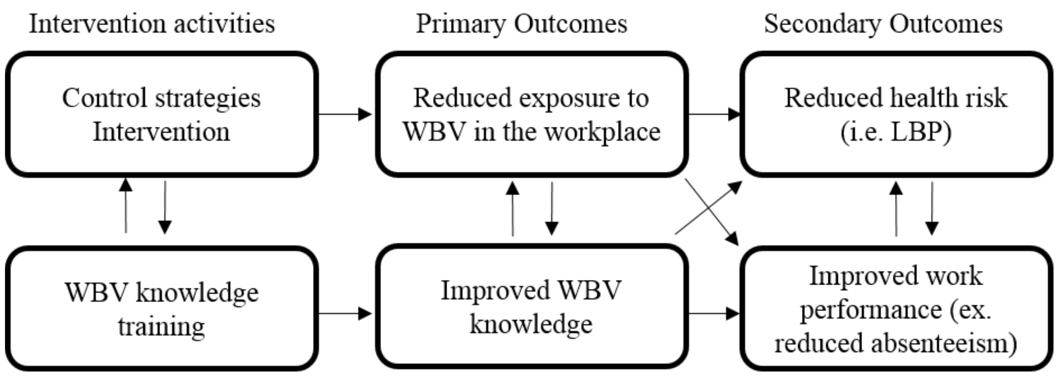

Figure 4.1 Intervention logic. Adapted from "An Integrated Approach to Workplace Mental Health: an Australian Feasibility Study", by A.D. LaMontagne et al., 2014, International Journal of Mental Health Promotion, 16(4), p.205-215.

4.2.3 WBV Knowledge Survey

All participants were asked to complete a brief baseline survey that assessed anthropometric measures, work history, and past vibration exposure. A short vibration knowledge survey, modelled after the WBV topic knowledge survey developed by Paschold and Sergeev (2009) (Table 4.1), was administered. The survey used a Likert-scale (KL1-5) to score a participant's perceived knowledge of WBV: 1 – none; 2 – awareness, but with limited understanding; 3 – basic understanding; 4 – most aspects, but lacking some detail; 5 – expert. The survey was given at baseline and follow-up, and scores (median response to the WBV knowledge questions) were subsequently compared to see if participants experienced changes in their perceived WBV knowledge.

Table 4.1 Questions for perceived WBV knowledge

Whole Body Vibration Knowledge – Survey Questions	
Q1	Rate your ability to define or explain whole-body vibration?
Q2	Rate your ability to identify or describe human health effects from exposure to whole-body vibration?
Q3	Rate your ability to identify or describe control strategies to reduce whole-body vibration exposure?
Q4	Rate your ability to measure or quantify exposure to whole-body vibration within your workplace?
Q5	Rate your ability familiarity with the Health Guidance Caution Zone (HGCZ) for assessment of whole-body vibration in the workplace (ISO 2631-1)?

Note. The survey uses a Likert-scale (KL1-5) to score a participants perceived knowledge of WBV: 1 – none; 2 – awareness, but with limited understanding; 3 – basic understanding; 4 – most aspects, but lacking some detail; 5 – expert.

4.2.4 Educational Sessions

After completing the baseline vibration knowledge survey each participant met with a member of the research team (one-on-one) three times during the intervention program to complete three educational sessions (Table 4.2). During the first session a WBVpod and booklet, Whole-body Vibration in Underground Mining, was distributed to each participant. The contents of the booklet included basic information on WBV, the associated health effects, control strategies to limit vibration exposure, as well as a section on the proper set up and use of the WBVpod. Throughout each session participants were encouraged to partake in discussions of the main topics for the particular session, and to provide any feedback on the usability of the WBVpod. The first session introduced the participants to some basic knowledge on WBV after completing the baseline survey for WBV knowledge. The second session focused on interpreting the readings from the WBVpod and the use of control strategies to limit one's exposure to WBV within the context of underground mining. Lastly, the third session had the participants provide feedback on the usability of the application and complete the post survey for WBV knowledge.

Table 4.2 Timeline for the delivery of the training program at the training and production sites

Training Site	
Week 1	• Baseline survey • Session 1: Introduction to WBVpod and WBV basic knowledge • Session 2: Control strategies
Week 2	• Session 3: Discussion on the usability of the WBVpod and Post survey
Production Site	
Week 1	• Baseline survey • Session 1: Introduction to WBVpod and WBV basic knowledge (health effects, control strategies etc.)
Week 2	• Session 2: Control strategies
Week 3-4	• Mine maintenance shutdown
Week 5-6	• Session 3: Discussion on the usability of the WBVpod and Post survey

Session 1: The first session introduced the participants to the term WBV, as well as its associated health effects. Lastly, participants were assigned an iPod touch with the accompanying WBV application, and given step-by-step instructions on how to use the WBVpod to monitor their levels of WBV exposure. The participants were encouraged to include supplementary information for trials such as the type of equipment being used, a task description, and the location of the task within the mine. The session concluded with having the participants demonstrate how to correctly position the measuring device on a seat.

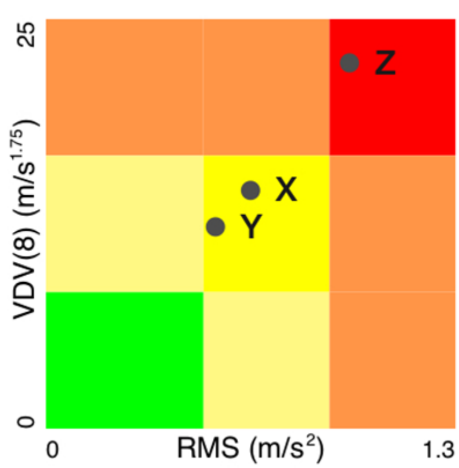

Figure 4.2 Graphic output of result screen for WBVpod

Session 2: The trials recorded to date by the participants were reviewed. The main focus was to ensure that the participants were able to properly interpret their vibration exposure trials with regards to the Health Guidance Caution Zone (ISO 2631-1, 1997) (Figure 4.2). Trials that measured vibration exposures that exceeded the upper boundaries of the Health Guidance Caution Zone (i.e. high health risk) would be coupled with a discussion of best-practice guides to reduce exposure to WBV. The booklet contained a section on control strategies: proactive road maintenance, seat and suspension maintenance, and the role of administrative controls in terms of training workers in seat adjustment, lower driving speeds, and smoother driving techniques. Participants were asked to review the list of control strategies and provide feedback on which practices were most practical or relevant to their work. Field notes were taken to provide insight into which control strategies the participants' chose to discuss.

Session 3: The third and final session required the participants to re-take the perceived WBV knowledge survey, as well as an exit survey for the participants to provide feedback on the usability of the WBVpod and supplementary training materials. Again, field notes were taken during the feedback discussion on the WBVpod. Upon completion of the surveys, the iPods, seat pads, and chargers were returned to the research team.

4.2.5 Procedure and Data Analysis

Scores for the WBV knowledge survey at baseline were compared to follow-up scores for each participant. The surveys used a Likert scale (1-none to 5-expert) to determine a participant's perceived WBV knowledge levels (KL1-5) on topics such as their ability to identify or describe human health effects from exposure to WBV, or their ability to identify or describe control strategies to reduce WBV exposure. A composite WBV knowledge score was calculated for participants based on their median response to the 5 knowledge questions. Improvement was determined based on changes in the composite knowledge scores after redoing the knowledge survey at the end of training program. A non-parametric (Mann-Whitney) test was used to determine if there was a significant difference between pre- and post-median test scores within subjects. A significance value of $p = .05$ will be indicative of a significant change in pre- and post-test scores.

It is hypothesized that after exposure to the WBVpod and accompanying best practice guide, the baseline WBV knowledge scores will be lower than the follow-up WBV knowledge scores. Further discussion can be found in the Appendix B.

4.3 Results

4.3.1 Demographics

4.3.1.1 Training Site

Eleven male trainees (n=11) successfully completed the baseline and follow-up surveys. A summary of participant demographics is shown in Table 4.3. All trainees had approximately 2-3 days of exposure to WBV by operating an LHD. The average age, weight and height of the participants was 28.36 years old (SD=6.71), 84.98 kg (SD=14.61), and 179.42 cm (SD=3.27) respectively. Ten of the participants (91%) stated that they were physically active. The amount of physical activity was further divided into the amount of exercise being done everyday (20%, n=2), more than 3 times per week (30%, n=3), 1-2 times per week (40%, n=4), and less than once a week (10%, n=1). Operating history and previous exposure to WBV varied; however, the majority of participants had limited experience and exposure since they were trainees. The average participant operated at least 2 types of mobile, earth-moving equipment, with an average

WBV exposure history of 4.05 years (SD=4.72). For previous employment, 55% (n=6) reported exposure to prolonged sitting; 91% (10) reported exposure to heavy physical demands; 82% (n=9) reported having to perform heavy lifting within 20 minutes of vibration exposure.

4.3.1.2 Production Site

Seven male mobile equipment operators (n=7) successfully completed the baseline and follow-up surveys after a 4-6 weeks intervention with the WBVpod. Participant demographics are summarized in Table 4.3. The average age, mass, and height of the participating production miners was 41.14 years old (SD=9.49), 99.27 kg (SD=16.90), 181.07 cm (SD=8.39) respectively. Fifty-seven percent (n=4) stated that they were physically active. The amount of physical activity was further divided into the frequency of exercise per week: 1-2 times a week (75%, n=3), and less than once a week (25%, n=1). The average participant operated three types of mobile, earth-moving equipment. The average WBV exposure history was 9.14 years (SD=4.02), with 86% (n=6) reporting an average, daily vibration exposure of greater than 4 hours; the remaining individual reported an average, daily vibration exposure of 3-4 hours. For previous employment, 100% (n=7) reported exposure to prolonged sitting; 71% (n=5) reported exposure to heavy physical demands; 86% (n=6) reported having to perform heavy lifting within 20 minutes of vibration exposure.

Table 4.3 Demographics for participants at the training and production mine.

Participant no.	Age (years)	Height (cm)	Mass (kg)	Vibration Exp. (years) (years)	Equipment Op. History (no.)*
Training Site					
1	23	177.8	72.57	1	2
2	40	185.42	97.52	2	2
3	21	177.8	95.25	5	5
4	25	175.26	63.50	1.5	2
5	28	177.8	86.18	1.5	1
6	19	177.8	73.48	2	2
7	26	180.34	77.11	8	5
8	29	177.8	70.31	15	1
9	31	180.34	94.80	2	4
10	31	185.42	111.13	5.5	3
14	39	177.8	92.99	1	3
Mean	28.4	179.4	84.99	4.0	-
SD	6.7	3.3	14.61	4.3	-
Median	-	-	-	-	2
Production Site					
1	29	185.42	102.06	8	3
2	36	180.34	83.91	14	6
3	46	172.72	87.09	4	4
4	34	195.58	124.74	11	7
5	38	170.18	88.45	8	5
6	56	182.88	88.45	5	4
7	49	180.34	120.20	14	3
Mean	41.1	181.1	99.27	9.1	-
SD	9.5	8.4	16.90	4.0	-
Median	-	-	-	-	4

*Note Equipment operating history refers to the number of different types of equipment that a participant has operated.

4.3.2 WBV Knowledge Survey

4.3.2.1 Training Site

Whole-body vibration knowledge level (KL1-5) was assessed using a Likert-scale survey. At baseline, 27% (n=3) of the participants had previously heard of the term WBV, and the median composite question score was 1, which translates to perceived WBV knowledge of none. At follow-up the median question score was 3, which translates to basic understanding. Feedback on the application was based on Likert-scoring of 1-strongly disagree to 5-strongly agree. Seventy-three percent of participants (n=11) agreed or strongly agreed to continued use of the WBVpod. Likewise, all participants (n=11) agreed or strongly agreed when asked whether they wanted to know their level of WBV exposure, and to recommending the WBVpod to a colleague.

4.3.2.2 Production Mine Site

Whole-body vibration knowledge level (KL1-5) was assessed using a Likert-scale. At baseline, 43% (n=3) of the participants had previously heard of the term WBV, and the median question score was 1 (none). At follow-up the median question score was 3 (basic understanding). Feedback on the application was based on Likert-scoring of 1-strongly disagree to 5-strongly agree. Fifty-seven percent (n=4) agreed or strongly agreed to continued use of the WBVpod. All participants (n=7) agreed or strongly agreed in wanting to know their level of WBV exposure, and 71.5% (n=5) agreed or strongly agreed to recommend the WBVpod to a work colleague.

4.3.2.3 Combinded Pre-Post Comparison

The median composite score from the post-survey was significantly higher than the baseline survey ($U=9.5$, $p < .05$) when evaluating the production and training mine site participants together (n =18) (Table 4.4).

Table 4.4 Comparison between median scores for pre- and post-surveys on perceived WBV knowledge which is a composite of each participant's response to the WBV knowledge questions

Production										
Participant no.	Q1		Q2		Q3		Q4		Q5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	3	3	2	**3**	2	**4**	1	**4**	1	**2**
2	3	**4**	2	**3**	2	**4**	1	**3**	1	**2**
3	1	**4**	1	**3**	1	**4**	1	**4**	1	**2**
4	1	4	1	**3**	1	**2**	1	**3**	1	**2**
5	1	**3**	1	**3**	1	**3**	1	**5**	1	**2**
6	1	**3**	1	**3**	1	**3**	1	**3**	1	**3**
7	1	**3**	1	**3**	1	**3**	1	**3**	1	1
Median	1	3	1	3	1	3	1	3	1	2

Training									
Participant no.	Q1		Q2		Q3		Q4		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
2	1	**4**	1	**4**	1	**4**	1	**4**	
3	3	**5**	3	**5**	3	**5**	3	**5**	
4	1	**3**	1	**3**	1	**3**	1	**4**	
5	3	2	2	**3**	3	1	2	**3**	
6	1	**4**	1	**4**	1	**3**	1	**3**	*
7	2	2	1	**2**	1	1	1	**2**	
8	1	**3**	1	**3**	1	**3**	1	1	
9	1	**4**	1	**3**	1	**4**	1	**3**	
10	1	**3**	1	**2**	1	**3**	1	**4**	
11	1	**3**	1	**3**	1	**3**	1	**3**	
14	1	**4**	1	**3**	1	**4**	1	**4**	
Median	1	3	1	3	1	3	1	3	

Note: The overall Median score is the resultant WBV knowledge level found for the group. Bolded numbers in the Post columns highlight =a higher score than the baseline. * Q5 was not included in the questionnaire for the trainee group.

4.3.3 WBV Exposure

4.3.3.1 Training Site

The trainees did at least one of three types of mucking tasks involving the LHD vehicle, for a total of eighteen trials. The task descriptions are based on observations and feedback from the supervisors and trainees. The first and third tasks (T1, T3) consisted of removing muck from within the mine, and disposing in a ‘discard’ pile at the surface. The main difference between T1 and T3 were the number of times the tasks were completed: T1 was completed 2-3 times and T3 was completed once. For task 2 (T2), the trainees were instructed to build up a muck pile within the mine (i.e. dozing), as well as scrapping the roads leading up to the muck pile. For the three types of tasks observed the average aRMS (SD) for the x-, y-, and z-axes are listed in Table 4.5.

Table 4.5 Mean frequency-weighted RMS (SD) for the three types of tasks measured with the WBVpod at the training site

Tasks	Mean Frequency-weighted RMS (m/s^2)		
	a_x	a_y	a_z
T1	0.45 (0.03)	0.32 (0.01)	0.48 (0.01)
T2	0.91 (0.20)	0.58 (0.09)	0.88 (0.21)
T3	0.50 (0.12)	0.35 (0.07)	0.38 (0.18)

The dominant axis (axis with the greatest magnitude of vibration) for the majority of tasks was the z-axis for T1, and the x-axis for both T2 and T3. The potential health risks based on the limit values for the HGCZ (0.47 – 0.93 m/s^2) were moderate for 14 of the 18 trials. There were two trials where health risks were low, both of which occurred in the T3 group. Lastly, two trials were classified as high risk, and both occurred in the T2 group.

4.3.3.2 Production Site

The 7 participants recorded a total of 80 trials over the 4-6 week study period across 16 pieces of equipment. The values of the vibration exposures (m/s^2) were represented across the HGCZ of the ISO 2631-1 (Table 4.6). The average aRMS and standard deviation (m/s^2) for the x-, y-, and z- axes was 0.42 (SD 0.17), 0.39 (SD 0.14), and 0.65 (SD 0.24), respectively. The z-axis (vertical) was the dominant axis in 79 of the 80 trials, with the lone trial having a dominant y-axis (lateral). The average aRMS and standard deviation (m/s^2) for all 80 trials was 0.65 m/s^2 (SD 0.24). If we assume an 8-hour duration based on the measured values, then the average aRMS value of 0.65 m/s^2 would translate to a moderate health risk based on the HGCZ (ISO 2631-1, 1997).

Sixteen different pieces of equipment were used by the participants, consisting of 8 LHD vehicles, 6 haulage trucks, 1 rock breaker, and 1 service truck. The average aRMS (m/s^2) for the LHD vehicles and haulage trucks were 0.70 m/s^2 (range: 0.40 – 0.92 m/s^2) and 0.55 m/s^2 (range: 0.34 – 0.78 m/s^2), respectively (Table 4.6).

4.4 Discussion

In both the training and production groups, an increase in perceived WBV knowledge was experienced at follow-up. Despite this, the majority of participants had a positive experience with the WBVpod. Participants expressed a general interest in knowing their level of WBV exposure, and an interest in continuing to use the WBVpod to monitor their daily exposure to WBV. Furthermore, given the short duration of exposure to the WBVpod and training materials (discussion of control strategies was done in the middle of the intervention period) in this pilot study, it would have been unlikely for the participants to adopt a control strategy and experience a significant reduction in WBV exposure values (see limitations section). For example, a study by Tiemessen et al., (2009) conducted 12-month intervention that consisted of consultations with occupational physicians. Despite the duration and intensity of the study, there was no significant reduction in WBV exposure.

4.4.1 Training Site versus Production Site

4.4.1.1 WBV Knowledge Survey

The median score was used instead of a mean score due to the small sample size. A mean value is more sensitive to outliers (i.e. the median is more robust) when dealing with small sample sizes and may not provide an accurate representation of the knowledge score. Overall, both sites experienced improvements in their composite knowledge scores based on the five questions on WBV knowledge when comparing pre- and post-survey scores. Pre-intervention scores showed median composite knowledge scores of 1(none) for both the training and production mine site participants respectively. Post-intervention scores showed a median composite knowledge score of 3 (basic understanding) for the training and production groups.

The perceived WBV knowledge composite scores at baseline between the sites were similar. The survey for the current pilot study was mirrored after the survey used by Paschold and Sergeev (2009), which looked at the WBV knowledge level of OHS and industrial hygienists in the U.S. They found that 69.5% of the participants self-reported a less than basic WBV understanding. Thus, it was expected that the baseline knowledge levels amongst the trainees and the production miners would be similar or lower. This lack of understanding highlights the importance of educating not only workers, but individuals at all levels of management (workers, supervisors, OHS departments, administration) to ensure that a hazard is recognized by all parties, and that compliance is endorsed at all levels of management (Goldenhar & Schulte, 1996; Hugentobler et al., 1992; Israel et al., 1992). While a difference in baseline scores between the groups may have been expected due to the differences in age and experience (28.4 and 41.1 years for the training and production site, respectively), because the topic of WBV was to new to the majority of participants in both groups the similarity in survey scores (median baseline score of 1; median follow-up score: 3) is not surprising.

Given the longer period of time spent using the WBVpod we would have expected this to be a contributing factor to the higher post-intervention scores experienced by the production mine site group. While the post-survey scores remained the same for both groups the feedback from the production mine site participants would carry more weight compared to the trainees who had limited time using the application.

4.4.1.2 Feedback on WBV Application and Training Material

The most common complaint about the WBV management program was discomfort associated with sitting on the custom-made seat pad designed to hold the WBVpod. Three of the seven (42.8%) participants at the production mine site and three of the eleven (27.3%) at the training mine site reported discomfort as the main reason for not wanting to continue to use the WBVpod. Participants at the production mine site were asked to sit on the seat pad for a longer duration (4-6 hrs) than the training mine site participants (1/2 – 1 hr) which could account for the higher percentage of participants at the production mine identifying discomfort as the reason for not wanting to continue to use the WBVpod. The reported discomfort is likely due to the design of the seat pad. Seat pad accelerometers for the gold standard device are slightly pliable, measuring 9.25 in. in diameter, and less than 0.5 in. thick at the center. The iPod seat pad was developed using Poly-tech 74 liquid rubber, providing a durable, yet flexible seat pad. However, to accommodate the size of the iPod the seat pad had a diameter of 6.5 in. and a thickness of 0.5 in. Although both seat pads ensured that the measurement devices were secure and properly aligned, the increased thickness of the iPod seat pad was likely responsible for the increased discomfort (Figure 4.3). Therefore, an improved seat pad should be developed to house the iPod for future applications. Creating a larger surface area would provide a more comfortable experience by evenly distributing the weight of the seated operator. Additionally, using a more cushioned material may address the discomfort issue.

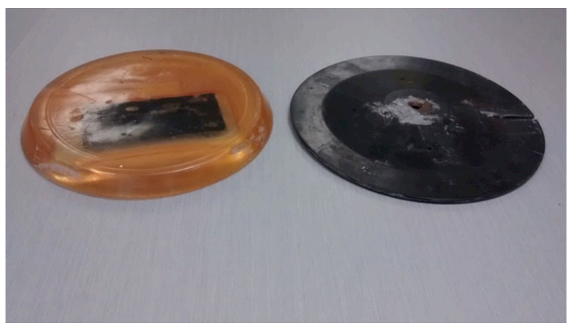

Figure 4.3 Custom rubber seat pad (left) and typical seat pad for tri-axial accelerometer (right); note the difference in thickness.

4.4.1.3 WBV Exposure

The WBVpod was used to measure WBV exposure on 18 (11 = training; 7 = production) participants for a total of 98 trials (18 = training; 80 = production). WBV exposure was recorded in all 3 axes (x, y and z) and expressed in r.m.s across the HGCZ. However, the data did show that participants are exposed to levels of WBV that are associated with a moderate health risk (Table 10). The values in Table 4.6 are the averages of the ar.m.s values from all the trials collected for the pieces of equipment used at the training and production mine site. These exposure values coincide with exposure values previously measured for LHD vehicles (Eger et al., 2006; Eger et al., 2011; Eger et al., 2013; Village et al., 1989), but are slightly lower for the haulage trucks (Eger et al., 2006) in underground nickel mining. Secondly, the collection of trials by the workers demonstrates that the workers are capable of using the application properly.

Table 4.6 Average frequency-weighted RMS for all trials based on the equipment operated by participants at the training and production mine site.

Location	Vehicle	Frequency-weighted RMS			HGCZ
		a_x	a_y	a_z	
Training	LHD 221	0.73	0.48	0.72	Moderate
	LHD 212	0.50	0.35	0.38	Moderate
Production	232 Cat Truck	0.27	0.24	0.44	Moderate
	253 Cat Truck	0.38	0.35	0.78	Moderate
	275 Cat Truck	0.28	0.26	0.48	Moderate
	276 Cat Truck	0.51	0.47	0.78	Moderate
	1058 Kiruna	0.26	0.30	0.47	Moderate
	1059 Kiruna	0.22	0.26	0.34	Low
	044 Rock Breaker	0.21	0.26	0.41	Low
	Truck 499	0.43	0.37	0.77	Moderate
	LHD 390	0.29	0.24	0.40	Moderate
	LHD 314	0.67	0.55	0.90	Moderate
	LHD 247	0.46	0.35	0.59	Moderate
	LHD 514	0.47	0.47	0.72	Moderate
	LHD 518	0.57	0.55	0.80	Moderate
	LHD 566	0.31	0.20	0.42	Low

The root-mean square (r.m.s.) exposure values can be normalized to an eight hour shift (A(8)), whereby a 20 minute measurement could provide an accurate representation of an operator's exposure to WBV for an entire shift (ISO 2631-1, 1997). Since the research team did not determine the total amount of time participants spent on the machine (i.e. being exposed to vibration) and off the machine (break, no vibration exposure) during a shift, we cannot say with certainty what the A(8) may be when using Equation (3): $A_n(8)$ is the frequency-weighted r.m.s acceleration values; a_n is the frequency-weighted r.m.s; T_{exp} is the daily duration of exposure to vibration; T_0 the reference duration of eight hours.

$$A_n(8) = a_n\sqrt{\frac{T_{exp}}{T_0}} \tag{3}$$

However, as long as the total exposure time is determined directly after measurement, such as those calculated in Table 4.7, the A(8) can be determined. Using the average vibration magnitude value for the 276 Cat truck, we can see that as the amount of on-time (vibration exposure) during an 8 hour shift decreases, so does the corresponding A(8). Nevertheless, these exposure data are of great importance for industries, researchers and workers that wish to measure WBV in any setting. One of the requirements for managing WBV is regular measurement. The WBVpod is an affordable, effective, and simple tool for routine WBV measurement that may allow workers to screen for high levels of WBV exposure in the workplace.

Table 4.7 Hypothetical A(8) values based on mean vibration magnitudes

Equipment	**Task**	**Duration of Exposure**	***Mean Vibration Magnitude on Seat (dominant axis)**	**A(8)**	****ISO 2631-1 HGCZ (based on an 8 hour exposure duration)**
		(hour)	(m/s^2)	(m/s^2)	
276 Cat Truck	On machine	7	0.78	0.73	within HGCZ
	Off machine	1	0		
276 Cat Truck	On machine	6	0.78	0.68	within HGCZ
	Off machine	2	0		

*Mean vibration magnitudes of dominant axis measured on the 276 Cat truck based on trials from several participants
**According to ISO 2631-1 the frequency-weighted acceleration values corresponding to the lower and upper limits of the HGCZ (for 8 hours of exposure) are 0.45 and 0.90 m/s^2 respectively.

4.4.2 Occupational Health and Safety Training

4.4.2.1 Engaging Educational Methods

The training materials used in this study, the combination of a booklet and two-way discussion with a research assistant, would be suitable for conveying knowledge on WBV; although a more engaging method, such as the K-W-L (Know, Want to Know, Learned) teaching model, would strengthen the degree of knowledge acquisition. The K-W-L begins with participants brainstorming everything they know about a certain topic, followed by a generating a list of questions about what they want to know about the topic, and lastly placing their new information in the learned column after completing a reading, lecture, or workshop (Ogle, 1980). When presenting facts the K-W-L model is useful because it is learner-focused, sets a purpose for a session, and allows participants to monitor their comprehension (Ogle, 1980). However, when it comes to improved behavioural performances, the current methods employed may be inadequate.

Emphasizing behaviour requires active participation through hands-on demonstration with behavioural simulations, such as observing a role model, modeling and practice, and feedback for modifying behaviour (Anderson, 1990; Bandura, 1986). Furthermore, the inclusion of action-focused reflection (thinking) would emphasize the benefits of improved behavioural performance by encouraging the participants to think with respect to the actions taken (Hacker, 2003; Burke et al., 2006). Improved behavioural performances would include the adoption of control strategies to eliminate or reduce WBV exposure, and would also include: monitoring and maintaining road conditions, job rotations to limit individual exposure time, lower vehicle speeds, or removal of the operator completely from the vibration source (i.e. remote mucking) (Paschold & Mayton, 2011). The more complex a behaviour, the more complex the training method: the strategies used to encourage routine tasks (ex. workers adjusting their seat) may not require the same complexity as a strategy directed to encourage more complex work place practices (ex. reduced driving speeds or improved route selection).

In the context of WBV, the increase in WBV knowledge (including knowledge on health effects and control strategies) would potentially translate to the adoption of controls strategies by the operator (reporting road conditions, adopting a less aggressive driving style) and an overall decrease in the duration and magnitude of WBV exposure. Given the short timeline and acute interactions with the participants, favourable behavioural changes would have been unlikely, and would have required a more intensive training method and support from workplace policies.

4.4.2.2 Compliance

Compliance is the degree to which an individual participates or engages in a practice, such as using the WBVpod to routinely measure vibration exposure. The degree to which operators participate in an intervention is a major influence on the changes in the outcome measures (Tiemessen et al., 2009). Tiemessen et al. (2009) had a group of 126 drivers of several equipment types (wheeled loaders, bulldozers, tractors etc.) consult with an OHS practitioner, whereby the two parties agreed on a set of control strategies that the driver would comply with (ex. route selection, driving speed, and driving style). No significant decreases in WBV exposure were seen between baseline and follow for the intervention group. However, drivers that were more than 50% compliant with the control strategies set out by the OHS practitioner showed a slight, yet not significant (P = 0.28), decrease in WBV exposure. Given the intensive methods used in the aforementioned study, the expectations for observing changes in behaviour and subsequent vibration exposure in the current study would be unrealistic. Since compliance was not a focus of the current study a brief discussion on the compliance outcomes can be found in Appendix B.

4.4.2.3 Control Strategies

The evaluation of control strategies to reduce WBV was not part of the pilot study. However, some of the thoughts and attitudes towards certain control strategies that were expressed by the participants are discussed in Appendix B.

Control strategies that focus on the individual, such as skills and behaviour, tend to be less expensive and easier to implement over a shorter-time period. This may include driving style, driving speed, or proper seat adjustment. Conversely, design considerations (types of suspension seating, vehicle suspension, cab design) and administrative controls (shift rotations, purchasing policies for equipment with low-emissions) will require more resources to implement. Nevertheless, the combination of both short- and long-term control strategies would be recommended for a successful intervention (Tiemessen et al., 2007).

Several barriers may impede the adoption of control strategies by workers/employers. These include the attitude of the workers towards the practicality of the strategy, such as reduced driving speeds. Participants within this study, as well as findings from previous WBV intervention studies demonstrated a pessimistic view towards reduced driving speeds due to the economic pressures and incentive to meet a quota. This reluctance may be further compounded by a perceived lack of peer support by fellow workers and employers, who may not believe that the strategies will lead to a more safe and productive workforce (Tiemessen et al., 2009). Therefore, the attitude towards long-term interventions may be improved by the prospect of receiving free-training and making the case for business – the costs from lost-productivity that could be reduced by addressing workplace risks and hazards (LaMontagne et al., 2010). Nevertheless, the WBV knowledge training and the WBVpod could be used as a way to pique interest among company stakeholders before the workplaces considers long-term commitments to control strategies for reducing WBV.

4.5 Limitations

There are some limiting factors to the extrapolation of these results. The average aRMS for the training mine site may not be reflective of the actual average aRMS for a LHD given the operating experience of the trainees, as well as the lower operating speeds (for safety purposes the LHDs were placed in first gear when used by a trainee). Overall these factors may not reflect the aRMS that would be measured in a production site. With the short timeline and limited time on the LHDs, a comparison between pre-post aRMS values could not be completed. It would be difficult to compare baseline and follow-up exposure values given that the conditions experienced during baseline may not be replicated at follow-up. These conditions may include the type of equipment being used, the physical environment (i.e. road conditions), or performing different tasks (ex. switching from high-vibration exposure of mucking with an LHD, to the low-vibration exposure of operating a Kiruna truck). A longer period of time would've allowed for more trials to be collected, which would provide a better representation of an individual's exposure at baseline and follow-up. Furthermore, a longer period of time would allow for more engaging educational methods (ex. simulations; active participation) to be used, as well as the implementation of workplace policies by supervisors and a management to support any control strategies that were undertaken by the workers. Lastly, the fact that control strategies were not discussed till week 2 at the production site further limits the likelihood that participants could successfully implement any of the control strategies discussed. Therefore, whether or not the use of the WBVpod and subsequent training material resulted in a lower degree of WBV exposure could not be ascertained.

Despite the positive feedback that was received by the WBVpod several issues were highlighted during the study. First off, the application was subject to random errors, whereby it would stop sampling during the measurement period. This error occurred more often during long measurement periods. This could be problematic for the workplace setting, where operators could be using a piece of equipment for several hours. Secondly, with longer measurement periods comes a larger amount of data for the application to process. As such the application would be stuck processing the data until it eventually succeeded or crashed. To avoid this issue the participants were told to set the WBVpod to create a sub-file every 20 minutes. If anything were to go wrong during the measurement period, instead of losing one large file only one of several sub-files would be lost. However, each 20-minute file has its own exposure values calculated, such that at the end of a long measurement period the operator would have difficulty interpreting their overall vibration exposure and subsequent health risk. Future versions of the

WBVpod should include an option to combine several trials to calculate WBV exposure values for a full shift.

Knowledge level was assessed by asking the participants to rate their understanding of WBV topics using a Likert scale. This method represents a participant's self-reported knowledge level rather than their actual knowledge level. Administering a test or exam would better represent a worker's actual knowledge level, and would therefore allow researchers to compare test scores to measure the level of knowledge acquisition after exposure to a training method. However, researchers would want to see improved knowledge acquisition (i.e. improved test score) translate to the adoption of desired safety behaviours. A worker may be able to define WBV, is familiar with the ranges of the HGCZ, and is able to list several control strategies, but does not incorporate this knowledge into practice. Improved awareness and understanding is only meaningful if it translates to adopting better practices. If more time were available with each participant the questionnaire used by Tiemessen et al., (2009) would have been more appropriate. The self-administered questionnaire used by Tiemessen et al. (2009) looked at knowledge, attitude, and behaviour towards WBV exposure. Knowledge was assessed using true and false questions (ex. WBV are caused mainly by bad track conditions). Both attitude and behaviour were assessed using a 4 point scale, and required participants to answer such questions about whether they did low back exercises while at work, or whether driving calmly in their job was impossible. A positive score for attitude or behaviour would indicate a positive attitude or change in behaviour towards strategies to decrease WBV exposure. A negative score would indicate a negative attitude or behaviour towards proposed strategies (Tiemessen et al., 2009). Overall, this approach would provide a more comprehensive understanding of a worker's knowledge on WBV, as well as the likelihood of complying with control strategies.

Alignment of the iPod was controlled as best as possible through demonstrations and practice during the initial educational session. During the training sessions the research assistants instructed the participants to demonstrate a proper setup of the WBVpod. Based on the demonstrations and simplicity of the setup, we are confident that the participants aligned the device properly throughout the study.

The delivery of the educational sessions and coordinating meetings with the participants faced several challenges. Firstly, the access to participants was limited to the brief moments before lining up for the cage to go to the underground mine site or after a shift when workers were keen to depart. This limited the amount of time to present and discuss the WBV topics and ultimately limited the amount of time for knowledge transfer. There were certain shifts called *surface days* where workers spent the day on the surface for meetings or training. Surface days would have been an ideal time to meet with participants, however, the surface days only occurred once a month per crew, and were further complicated by maintenance shut down and holiday/vacations. In the future delivery of the educational pieces on surface days would be ideal; however, the duration of the intervention would have to be longer on account of the surfaces days occurring 1-2 times a month.

The findings of our study may not be extrapolated across other industries or with other vibration exposure groups. Our study used a within-subject study design due to the low sample size (n=18). A within-subject study designs can be a threat to the internal and external validity of a study's findings. For example, internal validity can be threatened when using a pre-test, such that the pre-test can sensitize participants to a topic, changing their beliefs or behaviours. In the context of this study, participants may not have been aware of or concerned with WBV in the beginning. However, after having discussions on the associated health effects and control strategies the participants may change their beliefs or behaviours. Additionally, distinguishing which components of the intervention – the WBVpod, two-way discussion, and booklet - were the most effective cannot be easily distinguished.

Future studies should keep with the model that occupational injuries could be prevented by changing a workers' knowledge, attitude, and behaviour towards safety and task performance (Figure 4.1). The multifactorial nature of LBP risk includes chronic WBV exposure; therefore monitoring WBV exposure in conjunction with strategies that limit prolonged seating and awkward postures would be an effective approach. For WBV monitoring, the WBVpod would be instrumental in providing workers with a simple tool to monitor their vibration exposure. Qualitative methods, such as semi-structured interviews or focus groups, could also be used to gain a better understanding of how well an intervention has been adopted into the workplace. In the case of multiple studies with similar critical variables (i.e. vibration exposure, knowledge level), the use of standardised methods such as ISO 2631-1 for measuring vibration, or VIBRISK questionnaires for supportive work exposure history (Gallais et al., 2005; Tiemessen et al., 2004), would allow for the aggregation of data. Thus, if any observable effects of an intervention are present they will be able to rise above the noise created by all complex interactions of a workplace.

4.6 Conclusion

An iOS application, WBVpod, was used to measure WBV exposure among participants when operating mobile equipment at a training mine site and production mine site. The WBVpod and associated training material tended towards an increase in user-awareness and knowledge of WBV in the workplace. In addition, it highlighted that participants were, on average, exposed to moderate levels of WBV in reference to the ISO 2631-1 HGCZ. The limited interactions with the workers and the short follow-up made it difficult to determine whether or not the use of the WBVpod and subsequent training material resulted in a lower degree of WBV exposure.

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Chapter 5

5 General Discussion

Mobile equipment operators in underground mining are exposed to whole-body vibration (WBV) magnitudes that fall within or above the boundaries of the ISO-2631-1 Health Guidance Caution Zone (HGCZ). Recommendations to manage WBV exposure include routine monitoring. However, the ability to routinely measure WBV is hindered by the cost and complexity of the equipment. Chapter 3 validates the WBVpod against a gold standard device under a variety of laboratory and field conditions. The main findings from Chapter 3 are that the WBVpod is a valid tool for measuring WBV in the workplace. The amount of error appeared to be greater during the short (60-80sec) trials simulated in the laboratory. Thus it was suggested that the WBVpod performs best when used during trials of longer duration, which is similar to what would be encountered in the workplace. After validation Chapter 4 explored the effects of an intervention consisting of the WBVpod and educational sessions on a participant's perceived WBV knowledge level. A participant's composite knowledge score was based on several WBV topics such as their ability to measure WBV in their workplace or their familiarity with the HGCZ of the ISO 2631-1. The findings suggest that the intervention had a positive impact on the composite WBV score for the majority of participants and that the participants had an overall positive experience using the WBVpod. The relevance of the study's findings will be discussed in reference to industry, workers, researchers, and occupational health and safety specialists.

5.1 Industry

When implementing an intervention the support from stakeholders at all levels, from workers to management, is essential. While worker health and safety is one of the primary concerns of a workplace, productivity, wages, or work processes are also a top priority. Thus the success of interventions and control strategies not only relies upon the content of the intervention, but the context in which it is delivered and how stakeholders perceive it. As mentioned by LaMontagne et al. (2010), interventions that may negatively impact productivity may face resistance from both workers and management, because lower production could mean lower wages for the workers and less revenue for the company or industry. Therefore, the case for business (i.e. cost-benefit analysis) usually accompanies the introduction of an intervention in that the successful adoption of an intervention will lead to economic gains over the long-term due to such factors as a reduction in absenteeism or lost-time claims (Tompa et al., 2009; LaMontagne et al., 2014). While the WBVpod and accompanying educational pieces would not directly lead to a reduction in WBV exposure, it could provide an affordable and less intrusive approach for raising awareness about WBV exposure in the workplace, and perhaps highlight areas within the workplace or industry where harmful levels of vibration exposure are prevalent.

5.2 Workers

The simplicity and user-friendliness of the WBVpod could empower workers to monitor their vibration exposure, which in turn will hopefully encourage active participation in control strategies. The intuitive display of the results (Figure 5.1), helps a worker to distinguish whether he/she is in the red (high risk), yellow (moderate risk), or green (low risk) and can support/encourage the worker to initiate conversations with their supervisor, health and safety representative, or JHSC member about the risk of WBV and the possibility of implementing control strategies.

In addition to measuring vibrations, if workers are diligent in recording the task descriptions, equipment used, and location within the workplace they would be able to create a database overtime that can highlight areas of the mine or specific tasks that are associated with harmful levels of vibration exposure. These high-risk tasks or areas can then become the primary targets for control strategies. The hierarchy of control strategies (Cdcgov, 2016) from most effective to least effective is as follows: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). Organization-directed interventions that target controls further upstream in the hierarchy (ex. changing the physical environment through routine road maintenance) are more effective than individual-directed ones (ex. PPE). However, both organization- and individual-directed interventions should be used in conjunction to have the greatest effect on preventing both exposure and disease (LaMontange et al., 2007). Thus, the mere measurement and collection of vibration exposure is less meaningful if it does not influence policies and workplace practices.

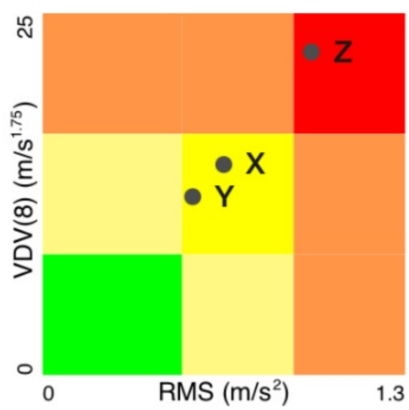

Figure 5.1 WBVpod screenshot of a results screen showing a high risk for adverse health effects in the z-axis (vertical).

5.3 Researchers

The WBVpod can be used by researchers to initiate vibration intervention studies with companies. Interventions can be divided into both short- and long-term segments (LaMontagne et al., 2015). Researchers and investigators who are hoping to implement an intervention into a workplace may begin through short-term practice such as WBV knowledge/literacy training. The literacy training acts to pique the interest of the stakeholders, particularly if the training is provided free-of-charge. The WBVpod could work in conjunction with the OHS literacy training by encouraging workers to take an interest in WBV by using a simple tool that they themselves can setup and interpret their own exposure levels. This short-term educational component can lay the groundwork for rolling out the long-term intervention strategies that would result in a change in workplace conditions such as improved seats, seat maintenance, and improved road maintenance/conditions).

The cost to directly measure WBV in the workplace during a study is often hindered by the cost and complexity in setting up the equipment. As such many studies rely on observations or self-reports to estimate daily vibration exposure. While these practices can provide acceptable predictions of daily vibration exposure (R^2= 0.26-0.6) (Village et al., 2012) there still remains a degree of uncertainty that could be addressed. The WBVpod could help reduce such issues by providing a simple and affordable method to directly measure daily vibration exposure during a study.

5.4 Occupational Health and Safety Professionals

Occupational health specialists include occupational health practitioners (OHP), Joint Health and Safety Committee (JHSC) members, health and safety representative, and industrial hygienists. While there are some differences in the roles and responsibilities of the aforementioned OHS professionals, they do share a common core set of responsibilities: identify workplace hazards, consult about workplace testing, make recommendations to employers, and investigate work refusals and serious accidents (Ontario Ministry of Labour, 2009). As noted by Paschold & Sergeev (2009), the majority of OHS specialists lack the knowledge to identify, investigate, and consult on WBV exposure in the workplace. Part of this lack of knowledge could include the

OHS professionals lacking the tools needed to monitor and mitigate WBV exposure in workers. Many work-related musculoskeletal disorders rely on self-reports for outcome variables, including WBV exposure. Self-reports can be influenced by social factors, and are not always practical in terms of the time and cost necessary to obtain. The WBVpod would be a suitable alternative for an OHS specialist to use in place of self-reports. The WBV measurement data in conjunction with the supportive work exposure history of a worker could allow for earlier recognition and intervention for clinically significant (i.e. high risk for adverse health effects) vibration exposures.

5.5 Future Applications and Research

In terms of using the application, an operator must stop the trial to allow the vibration exposure values to be calculated. This lack of real-time vibration measurement leads to an operator becoming aware of high-risk vibration exposure levels after the fact. This is not to say that the feedback is meaningless, only that the exposure values would be more meaningful if the operator was alerted before their vibration exposure values go into the ‘red’. The most meaningful outcome measures for occupational health and safety interventions are injury rates (Zwerling et al., 1997). However, some injury rates (the number of injury, illnesses, or lost workdays per 100 full-time workers) may be hard to capture due to long latency, assigning symptoms to a specific occupational exposure, and further classifying the severity of the injury (Zwerling et al., 1997). The utility of the intermediate outcomes depends on the acceptance of a causal model; can we use the intermediate outcomes along the way of the causal chain to measure efficacy of an intervention (Johnston et al., 1993). The hierarchy of outcome measures in terms of onset and meaningfulness are changes in knowledge, attitude, and behaviour; changes in the magnitude or duration of harmful levels of vibration; changes in injury rates (or delayed onset of LBP and sciatica or MSDs; decreased severity (i.e. incidence of LBP or MSDs remains constant, but the severity or number of cases that result in lost-time have been lowered).

The intermediate outcome used in the current study was knowledge (or perceived knowledge). Had the intermediate outcome been WBV exposure (A(8) or VDV_{total}) the WBVpod would have been a prime method for obtaining this information. Although the participants at the production mine site did collect exposure data, the primary focus was to obtain feedback on the usability of the WBVpod as an information tool for workers and not the exposure itself. Nevertheless, future studies that use vibration exposure as an intermediate outcome for interventions would benefit from the simplicity and affordability of the WBVpod. However, the use of the WBVpod in itself is not sufficient to limit a worker's exposure to high-levels of vibration. The simple measurement tool is only effective if 1) routine use of the WBVpod is encouraged by all levels of workers and management 2) implementation or changes to company policies that are paired with the measurements from the WBVpod.

The changes in policies may include administrative, behavioural, or engineering interventions. Training can encompass all three categories of interventions. While training is thought to be an administrative intervention (Harrison, 1989; LaMontagne et al., 1992; Michaels et al., 1992; Hugentobler et al., 1990), it can be paired with engineering and behavioural controls. For example, a new suspension seating that attenuates vibration exposure between the driver and the chassis may require training of the workforce for proper installation and usage. Simply implementing an engineering control may not lead to any meaningful reduction in the hazard. An engineering control may require training and behavioural changes to be effective (Zwerling et al., 1997; Parenmark et al., 1993).

Given that the two devices differed in their sampling rates, it was questioned whether the two outputs would be truly comparable. Using LabVIEW, an interactive graphical software program, the raw data that were sampled at 1000 Hz using the gold-standard device were re-sampled at the sampling frequency of the WBVpod, a nominal 89 Hz. However, if the sampling rate of the gold-standard device is altered, can it still be considered the gold standard? To simplify matters the data set was not manipulated. Ultimately, the goal was to determine if the vibration magnitude values that would be viewed by the worker were in agreement with the vibration magnitude values measured by the gold standard system, regardless of differences in technical specifications. While not necessarily a limitation, it should be noted that filter weight factors of *k* =1.0 were applied to all three axes, despite the fact that the WBVpod computes risk against the HGCZ. According to ISO 2631-1 (1997), when measuring WBV in relation to risk of health effects the filter weight (*k* factor) for the x and y-axes are typically set at 1.4, whereas the z-axis has a filter weight factor of k = 1.0. The ISO 2631-1 (1997) provides no rationale for using the k factor, or why the multiplying factor is higher when assessing health versus comfort (Burgess-Limerick & Maslen, 2012). Thus the WBVpod applies a *k* factor of 1.0 to all axes, which is equivalent to the protocol for assessing comfort using the ISO 2631-1 (1997) standard.

5.6 Conclusion

The WBVpod provides a simple and affordable method for measuring WBV exposure. Therefore, it can be a useful tool for workers, industry, manufactures, OHS specialists, and researchers. The laboratory and field validation portion of the study found the WBVpod to demonstrate an excellent level of agreement with the gold standard device, and recommends using the WBVpod for more lengthy measurements period as one would encounter in the workplace. The combination of the WBVpod and educational sessions during the intervention had a positive impact on a participant’s perceived knowledge level. While these findings do not suggest that the WBVpod and educational sessions would be solely responsible for improving workplace conditions, it does suggest that the two components (WBVpod and educational sessions) could be used as an entry into workplaces when integrated with WBV reduction practices and control strategies.

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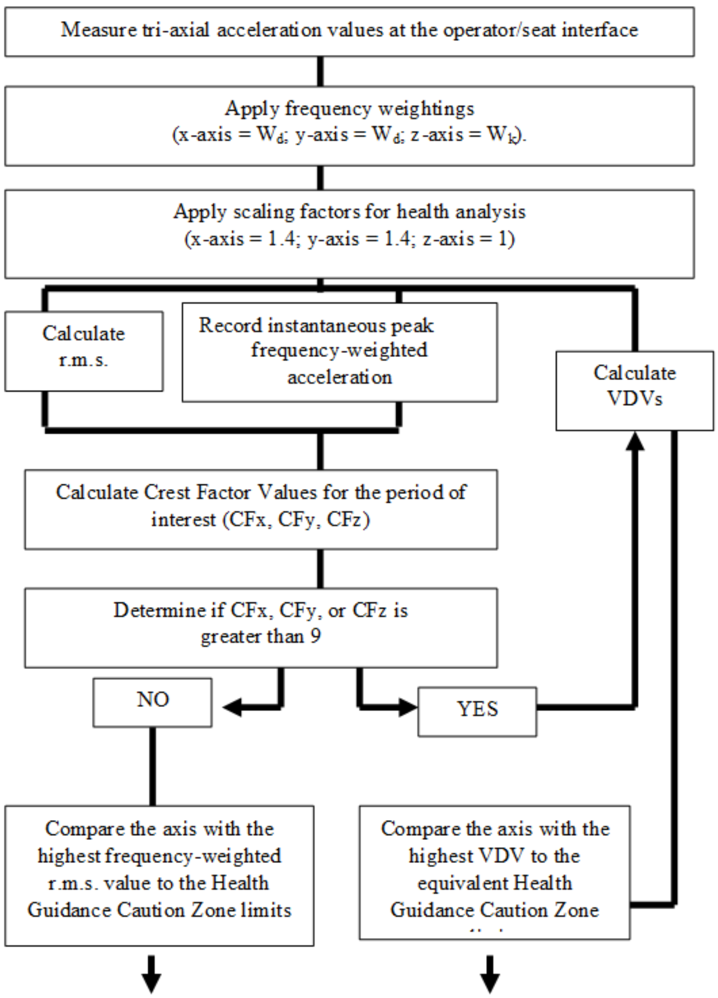
Appendices

Appendix A



A(8) (m/s^2)	VDV_{total} for 8 hours ($m/s^{1.75}$)	Health Risk
<0.45	<8.5	Low
0.45 – 0.90	8.5 – 17	Moderate
> 0.9	>17	High

Figure A1. Flow chart to determine health risks associated with WBV according to ISO 2631-1

Table A2. Vibration exposure data reported in the literature for mobile mining equipment in underground mining (Eger, T., Dickey, J.P., Oliver, M.L., Thompson, A.M.S. (2013). Occupational vibration exposure: understanding, evaluating and preventing health risks. World Mining Conference.)

Equipment Type	Application	Vibration Exposure		Vibration Exposure		Study Reference
		A(8) m/s^2	Health Risk[1]	VDV_{total} $m/s^{1.75}$	Health Risk[2]	
Haul Truck (16 ton)	underground nickel mine	1.20	high	----	---	Eger et al., 2006
Bulldozer	underground nickel mine	1.64	high	---	---	Eger et al., 2006
Bulldozer	surface coal mine	0.59	moderate	11.8	moderate	Burgess-Limerick, 2012
Grader	underground nickel mine	0.79	moderate	---	---	Eger et al., 2006
LHD (3.5 yard)	underground gold mine	1.12	high	---	---	Eger et al., 2006
LHD (3.5 yard)	underground mine	2.25	high	---	---	Village et al., 1989[3]
LHD (1.5-4 yards)	underground gold mine	1.7	high	34.0	high	Eger et al., 2011
LHD (3-6 yards)	underground gold mines	0.97	high	22.96	high	Eger et al., 2013
LHD (5 yard)	underground mine	1.04	high	---	---	Village et al., 1989
LHD (6 yard)	underground mine	1.6	high	---	---	Village et al., 1989
LHD (7 yard)	underground nickel mine	0.52	moderate	---	---	Eger et al., 2006
LHD (8 yard)	underground mine	1.24	high	---	---	Village et al., 1989[3]
LHD(6-11 yards)	underground nickel mines	0.82	moderate	19.94	high	Eger et al., 2013
LHD (8-11 yards)	underground nickel mine	1.0	high	22.5	high	Eger et al., 2011

1. Health criterion values based on the 8hr frequency-weighted rms acceleration:
High: above ISO 2631-1 Health Guidance Caution Zone (0.9 m/s^2) and above EU Directive 2002/44/EC daily exposure limit value (1.15 m/s^2).
Moderate: within the ISO 2631-1 Health Guidance Caution Zone (0.45-0.9 m/s^2)
Low: below the ISO 2631-1 Health Guidance Caution Zone (0.45 m/s^2) and below the EU Directive 2002/44/EC daily exposure action value (0.5 m/s^2)

2. Health criterion values based on the vibration total value:
High: above the ISO 2631-1 Health Guidance Caution Zone (17 $m/s^{1.75}$) and EU Directive 2002/44/EC daily exposure limit value (21$m/s^{1.75}$).
Moderate: within the ISO 2631-1 Health Guidance Caution Zone (8.5 $m/s^{1.75}$ -17 $m/s^{1.75}$)
Low: below the ISO 2631-1 Health Guidance Caution Zone (8.5 $m/s^{1.75}$) and EU Directive 2002/44/EC daily exposure action value (9.1 $m/s^{1.75}$)

3. Processed according to ISO 2631 (1978)

Appendix B

Table B1 does not display any apparent trends between the number of trials completed and the change in perceived WBV knowledge score at follow up. If anything the participants who had never heard of WBV or had limited knowledge experienced the greatest change in score. This change in score is not surprising as participants with little to no prior knowledge of WBV would require less training and knowledge acquisition to experience a perceived change in WBV knowledge, whereas a participant with prior knowledge of WBV would be expected to require more training and knowledge acquisition to experience a similar change in perceived knowledge.

Table B1. Interaction of participation (trials completed) on post-test scores for perceived WBV knowledge

Participant no.	Trials completed	Pre-test score	Post-test score	Change in Score	Continued Use (Q1)
1	6	2	3	1	4
2	44	2	3	1	4
3	18	1	4	3	1
4	0	0	3	3	4
5	1	0	3	3	4
6	1	0	3	3	1
7	12	0	3	3	2
Overall	11.7 (avg)	0 (mdn)	3 (mdn)	3 (mdn)	4 (mdn)

The participants believed that the most practical control strategies would be through engineering controls: better seat design, better cab design, and advancements in remote-control practices (remote mucking). Based on the discussion with participants on controls strategies the most frequently mentioned control strategies were in the context of seating, driver behaviour, and road conditions (Table B2 and B3). Seat design has been successful in limiting WBV exposure in underground mining equipment. Mayton et al., 2009 evaluated seat design on shuttle cars at an underground coal mine. The seats in question were designed by the NIOSH, which had supposed improved vibration attenuation and comfort from use of foam padding and low-back support. The perception of jolts/jars and discomfort based on a visual analog scale (VAS) and questionnaire rating were compared to direct WBV measurements. Results showed a considerable improvement in WBV exposure (19-46% reduction relative to existing seats) and operators' ratings. It was estimated that health and safety of approximately 1,980 shuttle car operators were improved once the improved seat design was later adopted in 51% of shuttle cars in the U.S. market. Factors such as seat performance could be routinely monitored based on vibration amplification/attenuation between the floor and seat pan. As noted by Tiemessen et al. (2009) workers typically showed reluctance to changes in driving behaviour (i.e. reduced driving speed) where there are pressures for economic productivity. While this attitude was noted by some of the participants in the current study, it is by no means a representation of the company's attitude.

Table B2. Quotations from participants during discussion of control strategies during educational sessions

Control Strategies	Knowledge of Control Strategies
Reduced driving speeds	P.5 “May be in rush when there is the incentive of a bonus. Also there are no speed limits signs in veins.” P.7 “No one is trying to break any records, we still slow down and check our corners.”
Road conditions	P.5 “Grader on main ramp is maintained consistently; other areas are less consistent.” P.1 “Roads are maintained as best they can, may miss a few rough spots.” P.3 “Road ways should be smooth like the lobby floor, but poorly managed by road crew.” P.2 “Sump pumps are not always working - poor road conditions.”
Seating and other equipment	P.5 “Different machines have different types of seat (mechanical and air-ride), don’t know which is better or suitable.” P.1 “Better suspension would be nice; air ride suspension newly installed, but after 6-8 months they are bottoming out (worn out), especially for the heavier operators.” “Best approach would be to have the proper equipment to begin with, the rest would depend on driver behaviour.” P.3 “Really old truck; seats in Kiruna haul trucks are 2 years old and have shoulder straps (due to an accident).” P.4 “Proposed future study whereby WBVpod is used for 6 months in an LHD with different seats to see which ones are better.”
Driver behaviour	P.5 “I will keep the bucket low and scrape the road to remove smaller debris so you are not constantly driving over bumpy areas.” P.7 “I check my roadways first and check my seat setting: five guys of different weights and sizes can cycle through a single LHD in between when I use it.”
General feedback	P.2 “If this is something (WBV) that could deteriorate my health I would want to know.” P.1 “When completing a rough task, the readings on the WBVpod are very low or provide no reading; I think they are incorrect.”

Table B3. 10 most frequent words used in discussion of control strategies with production mine participants

Rank	Word
1	Road
2	Different
3	Check
4	Better
5	Know
6	Best
7	Rough
8	Low
9	Maintained
10	Seat

Appendix C

Baseline Survey

Part A: Background Information

1. Gender_________

2. What is your current age?_________

3. What is your current weight? (lbs)_________

4. What is your current height? (feet/inches)_________

5. Do you exercise?
   - o Yes
   - o No

6. If you answered YES to question 5 how often do you take part in vigorous exercise each week?
   - o Never
   - o Less than 1 time
   - o 1-2 times
   - o 3 times or more
   - o Everyday

Part B: Work and Equipment Operation History

7. Have you previously operated equipment that exposes you to whole-body vibration?
   - o Yes
   - o No

If you answered NO please go to Part C; if you answered YES please answer the following:

8. What types of equipment have you operated?
   - o LHD (scoop)
   - o Haul truck
   - o Jumbo

- Forklift
- Tractor
- Dozer

8. (Continued)

- Loader
- Other (please list):____

9. How many years have you operated equipment that exposed you to whole-body vibration? ________

10. How many hours a day (on average) did you operate or work with equipment that exposed you to vibration?

- None
- Less than 1
- 1-2
- 3-4
- More than 4

11. Did your job involve prolonged sitting?

- Yes
- No

12. Did your job involve heavy physical demands?

- Yes
- No

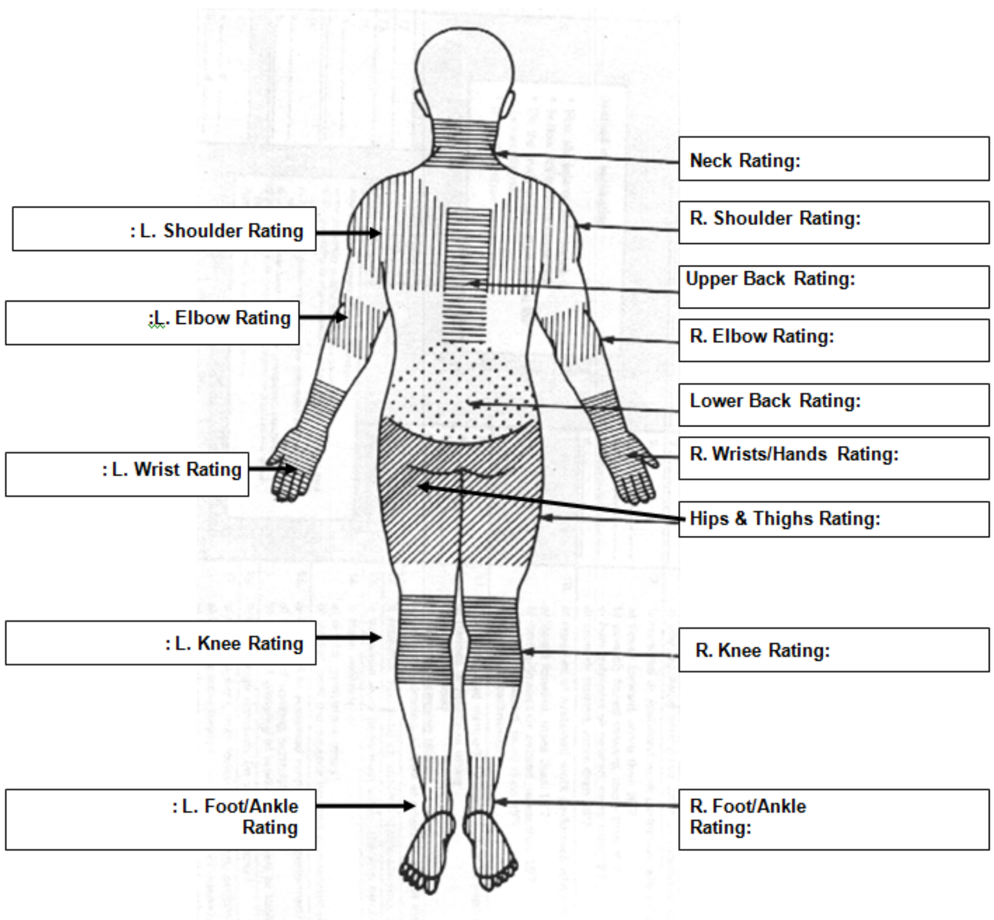
13. Did your job involve lifting/moving weights of 20 lbs (10 kg) or more within 20 minutes of being exposed to vibration?

- Yes
- No

Part C: Musculoskeletal Disorders

The body has been divided into fourteen different regions (right). For each body region please indicate if you have had any trouble (ache, pain, numbness or discomfort) in the region in the last 6 months. If you have had trouble in the area in the last 6 months rate the severity of the trouble, at the worst episode that you felt.

Rating Score
1 = mild ache, pain, numbness or discomfort
2 = moderate ache, pain, numbness or discomfort
3 = severe ache, pain, numbness or discomfort
4 = very, very severe ache, pain, numbness or discomfort



Part D: Whole-body Vibration Knowledge

This section of the survey will assess your knowledge level on whole-body vibration and associated standards.

14. Have you heard of the term whole-body vibration (WBV) before?

- Yes
- No

If you answered NO please return your survey to the research team. If you answered YES please answer the following questions:

15. Where have you FIRST heard of or learned about whole-body vibration?

- Instruction/training program
- Preparation for certification exam
- Publications
- In conversation
- Website
- Other (please specify)__________

16. When did you first hear of or learn about whole-body vibration?

- Less than 2 yrs
- 3-4 yrs
- 5-6 yrs
- 7-8 yrs
- More than 8 yrs

17. Rate your ability to define or explain whole-body vibration?

- 1 (none)

- ○ 2 (awareness, but with limited understanding)
- ○ 3 (basic understanding)
- ○ 4 (most aspects, lacking some detail issues)
- ○ 5 (expert)

18. Rate your ability to identify or describe human health effects from exposure to whole-body vibration?

- ○ 1 (none)
- ○ 2 (awareness, but with limited understanding)
- ○ 3 (basic understanding)
- ○ 4 (most aspects, lacking some detail issues)
- ○ 5 (expert)

19. Rate your ability to identify or describe control strategies to reduce whole-body vibration exposure?

- ○ 1 (none)
- ○ 2 (awareness, but with limited understanding)
- ○ 3 (basic understanding)
- ○ 4 (most aspects, lacking some detail issues)
- ○ 5 (expert)

20. Rate your ability to measure or quantify the exposure to whole-body vibration within your workplace?

- ○ 1 (none)
- ○ 2 (awareness, but with limited understanding)
- ○ 3 (basic understanding)
- ○ 4 (most aspects, lacking some detail issues)
- ○ 5 (expert)

21. Rate your familiarity with the Health Guidance Caution Zone (HGCZ) for assessment of whole-body vibration in the workplace (i.e. ISO 2631-1).

- 1 (none)
- 2 (awareness, but with limited understanding)
- 3 (basic understanding)
- 4 (most aspects, lacking some detail issues)
- 5 (expert)

Appendix D

Follow-up Survey

Part A: Whole-body Vibration Knowledge

1. Rate your ability to define or explain whole-body vibration?

- 1 (none)
- 2 (awareness, but with limited understanding)
- 3 (basic understanding)
- 4 (most aspects, lacking some detail issues)
- 5 (expert)

2. Rate your ability to identify or describe human health effects from exposure to whole-body vibration?

- 1 (none)
- 2 (awareness, but with limited understanding)
- 3 (basic understanding)
- 4 (most aspects, lacking some detail issues)
- 5 (expert)

3. Rate your ability to identify or describe control strategies to reduce whole-body vibration exposure?

- 1 (none)
- 2 (awareness, but with limited understanding)
- 3 (basic understanding)
- 4 (most aspects, lacking some detail issues)
- 5 (expert)

4. Rate your ability to measure or quantify exposure to whole-body vibration within your workplace?

- 1 (none)
- 2 (awareness, but with limited understanding)
- 3 (basic understanding)
- 4 (most aspects, lacking some detail issues)
- 5 (expert)

5. Rate your ability familiarity with the Health Guidance Caution Zone (HGCZ) for assessment of whole-body vibration in the workplace (ISO 2631-1).

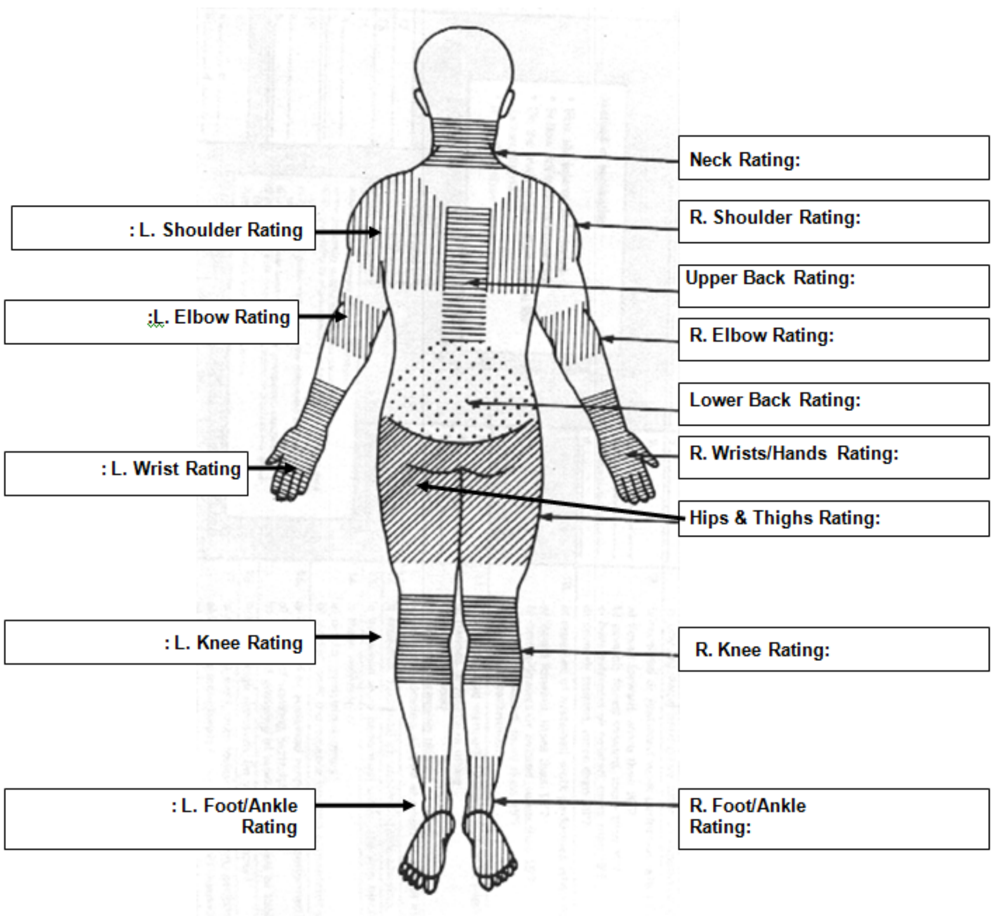
- 1 (none)
- 2 (awareness, but with limited understanding)
- 3 (basic understanding)
- 4 (most aspects, lacking some detail issues)
- 5 (expert)

CONTINUE TO PART B

Part B: Musculoskeletal Disorders

The body has been divided into fourteen different regions (right). For each body region please indicate if you have had any trouble (ache, pain, numbness or discomfort) in the region since the **baseline survey measurements**. If you have had trouble in the area since the baseline survey rate the severity of the trouble, at the worst episode that you felt.

Rating Score
1 = mild ache, pain, numbness or discomfort
2 = moderate ache, pain, numbness or discomfort
3 = severe ache, pain, numbness or discomfort
4 = very, very severe ache, pain, numbness or discomfort



Part C: WBVpod and Discussions/Explanations Feedback

Please rate the following on a scale from 1 to 5:

Strongly Disagree (1) – Disagree (2) – Unknown (3) – Agree (4) – Strongly Agree (5)

1. I would continue to use the WBVPod.

1 2 3 4 5

2. The discussions/explanations were useful in explaining how to use the WBVpod.

1 2 3 4 5

3. The discussions/explanations were presented in a clear and organized manner.

1 2 3 4 5

4. I like to know my daily exposure to whole-body vibration.

1 2 3 4 5

5. Knowledge of my daily exposure to whole-body vibration helps me identify control strategies to reduce my daily exposure to whole-body vibration.

1 2 3 4 5

6. Knowing my daily exposure to whole-body vibration, I would be more comfortable to approach my supervisor(s) about any concerns regarding whole-body vibration.

1 2 3 4 5

7. I would recommend the use of the WBVpod to a work colleague.

1 2 3 4 5

8. Please provide any additional comments or feedback about the WBVpod and whole-body vibration discussions/explanations that you would like to share with the research team.

Appendix E: Ethics Certificate

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension

Name of Principal Investigator and school/department	Tammy Eger, Human Kinetics
Title of Project	Validation and Efficacy of a Simple Tool for WBV Measurement and Exposure Management
REB file number	2015-05-08
Date of original approval of project	June 12, 2015
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on: *(You may request an extension)*	June, 2016
Conditions placed on project	

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate LU REB form. In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations and best wishes in conducting your research.

Rosanna Langer

Rosanna Langer, PHD, Chair, *Laurentian University Research Ethics Board*