DOSE RESPONSE RELATIONSHIP BETWEEN WHOLE BODY VIBRATION (WBV) AND LOW BACK PAIN (LBP) AMONG DIFFERENT TYPES OF VEHICULAR DRIVERS IN THE STATE OF SABAH

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THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PUBLIC HEALTH

FACULTY OF MEDICINE
UNIVERSITY OF MALAYA
KUALA LUMPUR

2018

ORIGINAL LITERARY WORK DECLARATION

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Registration/Matric No: **MHC 100005**

Name of Degree: **Doctor of Public Health**

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

DOSE RESPONSE RELATIONSHIP BETWEEN WHOLE BODY VIBRATION (WBV) AND LOW BACK PAIN (LBP) AMONG DIFFERENT TYPES OF VEHICULAR DRIVERS IN THE STATE OF SABAH

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ABSTRACT

Effect of whole body vibration (WBV) to the human spine is determined by a combination of vibration magnitude and duration of exposure. This study aimed to ascertain the dose response relationship between WBV and low back pain (LBP) among drivers in state of Sabah. A cross sectional study was conducted among 155 male drivers (predominantly Kadazan/Dusun) operating a different type of vehicles. Measurements of WBV exposures were conducted in strict compliance with ISO 2631-1 requirements. A structured interview using a standardized questionnaire was conducted to assess LBP, individual characteristics, and other work-related risks factor. Postural risks to LBP were assessed via direct observation. Vibration exposures were calculated based on a daily [acceleration equivalent over an eight hours reference period express in A(8) for root-mean-square (r.m.s) and Vibration Dose Value (VDV) for root-mean-quad (r.m.q)] and cumulative measures [acceleration express in the form of $\sum a_i^m T$ where a_i is the means of vibration magnitude in a_{ws} and a_{wq} (frequency weighted in r.ms and r.m.q respectively), T is the total hours of exposure and *m* in the order of zero, one, two or four]. The log form of the doses divided into four quartiles and regressed against a symptom of LBP. Based on health risks analysis following the health guidance caution zone (HGCZ) severe form of daily WBV exposures expressed in VDV as about 99.4% exceeded the recommended values as opposed to daily exposures expressed in A(8) as only 9.0%. At univariate analysis, several individual factors (higher education attainment, non-alcoholic, smoking and presence of MSD other than lower back region) and work-related factors (involvement in part-time job, work schedule following office hours and posture against backrest while driving) were significantly associated with symptoms of LBP. In the multiple logistic regressions after adjustment of the potential confounders, there was a significant increase in the odds of developing LBP with WBV observed using the cumulative dose measures. At LBP past 12 months drivers exposed to Dose 3 and Dose

6 [$\ln(a_{ws})^2T$ and $\ln(a_{wq})^2T$] in quartile two reported with (aOR = 2.822, 95% C1 1.038 to 7.668) and (aOR = 2.981, 95% CI 1.096 to 8.104) respectively. At LBP past four weeks drivers exposed to Dose 2, Dose 3, Dose 5 and Dose 6 [$\ln(a_{ws})T$, $\ln(a_{ws})^2T$, $\ln(a_{wq})T$ and $\ln(a_{wq})^2T$] in quartile two reported with (aOR= 3.667, 95% CI 1.399 to 9.613), (aOR= 2.649, 95% CI 1.206 to 6.838), (aOR = 3.303, 95% CI 1.273 to 8.570) and (aOR = 3.852, 95% CI 1.455 to 10.193) respectively. In the occurrence of LBP post driving, only one statisticallyly significant result observed at quartile two for Dose 2 [$\ln(a_{ws})T$] with (aOR = 4.208, 95% CI 1.442 to 12.277). The finding indicates dose response relationship between increasing exposures of WBV and occurrence of LBP among professional drivers. The first [$\ln(a_{ws})T$ and $\ln(a_{wq})T$] and second [$\ln(a_{ws})^2T$ $\ln(a_{wq})^2T$] orders for cumulative dose measures were more predictive in comparison to daily measures of A(8) and VDV.

ABSTRAK

Kesan getaran seluruh badan (Whole Body Vibration,WBV) kepada tulang belakang manusia ditentukan oleh kombinasi magnitud getaran dan tempoh pendedahan. Kajian ini bertujuan untuk menentukan hubungan tindakbalas dos antara pendedahan WBV dengan simptom sakit belakang bawah (Low Back Pain, LBP) dalam kalangan pemandu di kawasan iklim tropika. Kajian keratan rentas dilakukan ke atas 155 pemandu lelaki (sebahagian besarnya Kadazan / Dusun) yang memandu pelbagai jenis kenderaan. Pengukuran pendedahan WBV dilakukan mengikut garis panduan ISO 2631-1. Soal selidik berstruktur digunakan untuk menilai simptom LBP, ciri individu dan faktor risiko berkaitan yang lain, sementara penilaian risiko postur dilakukan melalui pemerhatian langsung. Pendedahan getaran dikira berdasarkan pada dos harian [bersamaan pecutan dalamt tempoh lapan jam masa rujukan dan dinyatakan dalam A(8) untuk nilai punca min persegi (r.m.s) dan nilai dos getaran (VDV) untuk punca min quad (r.m.q)] dan dos kumulatif [pecutan dinyatakan sebagai $\Sigma a_i^m T$ dimana a_i adalah magnitud getaran dalam a_{ws} dan a_{wq} (frekuensi getaran dilaporkan dalam r.m.s dan r.m.q masing-masing), T ialah jam keseluruhan pendedahan dan m dalam urutan kosong,satu, dua atau empat]. Dos yang telah ditukarkan kepada bacaan log dibahagikan kepada empat kuartil dan diregreskan terhadap kejadian simptom LBP. Analisis risiko kesihatan yang berasaskan pendedahan harian WBV berdasarkan *Health Guidence Cuation Zone* (HGCZ) yang dinyatakan dalam VDV adalah 99.4% dilaporkan melebihi nilai yang disyorkan berbanding dengan pendedahan harian yang dinyatakan dalam A(8) adalah 9.0%. Pada analisis univariat beberapa faktor individu (pencapaian pendidikan tinggi, tidak mengambil alkohol, perokok dan mengalami MSD selain daripada kawasan bawah belakang) dan faktor-faktor yang berkaitan dengan pekerjaan (penglibatan dalam kerja sambilan, jadual kerja mengikut waktu pejabat dan postur bersandar semasa memandu) mempunyai perkaitan dengan kejadian simptom LBP. Dalam regresi logistik berganda selepas pelarasan

pengungkapan yang berpotensi, terdapat peningkatan yang signifikan dalam kemungkinan mendapat LBP dengan WBV yang diamati menggunakan langkah-langkah dos kumulatif. Pada kejadian LBP 12 bulan sebelum Dos 3 dan Dos 6 [ln $(a_{ws})^2$T dan ln $(a_{wq})^2$T] yang dilaporkan dalam OR yang diselaraskan bagi pemandu yang menerima dos dalam kuartil kedua adalah (aOR = 2.822, 95% C1 1.038 hingga 7.668) dan (aOR = 2.981, 95% CI 1.096 hingga 8.104) masing-masing. Pada kejadian LBP empat minggu sebelum Dos 2, Dos 3, Dos 5 dan Dos 6 [ln(a_{ws})T, ln$(a_{ws})^2$T, ln(a_{wq})T dan ln$(a_{wq})^2$T] yang dilaporkan dengan OR yang diselaraskan bagi pemandu yang menerima dos pada kuartil kedua adalah (aOR = 3.667, 95% CI 1.399 hingga 9.613), (aOR = 2.649, 95% CI 1.206 hingga 6.838), (aOR = 3.303, 95% CI 1.273 hingga 8.570) dan (aOR = 3.852, 95% CI 1.455 hingga 10.193) masing-masing. Dalam kejadian LBP berkaitan dengan pemanduan hanya satu keputusan signifikan yang diperhatikan pada kuartil kedua Dos 2 [ln(a_{ws})T] dengan (aOR = 4.208, 95% CI 1.442 hingga 12.277). Penemuan ini menunjukkan terdapat hubungan tindak balas dos antara peningkatan pendedahan WBV dengan kejadian LBP dalam kalangan pemandu profesional. Pengiraan dos kumulatif menggunakan urutan pertama [ln(a_{ws})T dan ln(a_{wq})T] dan kedua [ln$(a_{ws})^2$T, ln$(a_{wq})^2$T] dapat meramalkan kejadian simptom LBP berbanding dengan pengiraan dos harian meliputi A(8) dan VDV.

ACKNOWLEDGMENTS

Firstly, I would like to expressed my gratitudes to the Almighty for allowing me to experience this journey. Secondly, my gratitudes goes to my contents supervisor, Assoc.Professor Dr. Anselm Su Ting and to my methods supervisor Assoc.Professor Dr. Moy Foong Ming for their continuous assistance, guidance and expert opinions. Their patience and persistant encouragement gave me energy to persevere till the completion of this study.

Thirdly, my deepest appreciation goes to all the private companies and government departments that participated in this study. Without their participation this study would not have been possible. Special thanks goes to to my main sponsor PSD, and MOH Malaysia. Not forgetting University of Malaya for provding finacial assistance through the Post-graduate Research Funds.

To all the ‘crazy’ bunch of people I call “tambalut”, I am not able to mention your individual names, but I know you have directly contributed to the completion of this book. I will never be able to repay for the kind gasture and deeds. Not to forget the brethren who underwent the similar journey. Together we struggled to reach our destination, but that made us stronger and full of perseverance. We are survivers among the fittests.

Last but not least to my loving parents, my only sister and only brother, uncles, aunties, cousins, nices, nephews, brother and sister in laws and the extended families, you molded me to who I am today. I know you all never gave up praying for my success. May God continues to bless all of you.

“ if you can dream it, you can do it”
Walt Disney

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

WBV : Whole Body Vibration
LBP : Low Back Pain
VDV : Vibration Dose Value
EAV : Exposure Action Value
ELV : Exposure Limit Value
JKKP : *Jawatankuasa Keselamatan dan Kesihatan Pekerjaan*
OR : Odds Ratio
aOR : Adjusted Odds Ratio
r.m.s : Root Mean Square
r.m.q : Root Mean Quad
MMH : Material Manual Handling
MSD : Musculoskeletal Disorders
PMH : Past Medical History
ISO : International Organization for Standardization
Q : Quartiles
PSD : Public Service Department
MOH : Ministry of Health
HWE : Healthy Worker Effect
RR : Relative Risks
HGCZ : Health Guidance Caution Zone
CDL : Competent Driving License
VDL : Vocational Driving License
NMQ : Nordic Musculoskeletal Questionnaire
MRI : Magnetic Resonance Imaging
ASL : Acquired Spondylolisthesis
POMS : Profile of Mood States
PSS : Perceived Stress Score
JCQ : Job Content Questionnaire
VAS : Visual Analogue Scale
NSR : Numerical Rating Scale
LCA : Latent Class Analysis
OWAS : Ovako Working Analysis System
RULA : Rapid Upper Limb Assessment
PEIA : Participatory Ergonomics Intervention Approach

Hz : Hertz

CF : Crest Factor

MTVV: Maximum Transient Vibration

BS : British Standard

TLV : Threshold Limit Value

BMD : Bone Mineral Density

DOSM: Department of Statistics Malaysia

BMI : Body Mass Index

MetS : Metabolic Syndrome

ICD : International Classification of Diseases

SMR : Standardize Mortality Ratio

ILS : Integrated Logistics Services

ILLS : International Integrated Logistics Services

EPU : Economic Planning Unit

GHQ : General Health Questionnaire

IQR : Interquartile Range

MPV : Multipurpose Vehicles

SUV : Sport Utility Vehicles

a_v : Acceleration magnitude expressed in vector sums

a_{wx} : Acceleration magnitude expressed in x-axis

a_{wy} : Acceleration magnitude expressed in y-axis

a_{wz} : Acceleration magnitude expressed in z-axis

a_{ws} : Acceleration magnitude expressed in r.m.s

a_{wq} : Acceleration magnitude expressed in r.m.q

A(8) : Daily Dose Exposure expressed in r.m.s over eight hours reference

S : Sacral region of the spine

L : Lumbar region of the spine

EU : European Union

IRR : Incidence Rate Ratio

IDD : Intervertebral Disc Degeneration

PG : Prostaglandin

CVD : Cardiovascular Disease

GIT : Gastrointestinal Tract

KEJARA: *Kesalahan Jalan Raya*

HSE : Health and Safety Executive

USB : Universal Serial Bus

sq : Square

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background

Occupational related low back pain (LBP) has been extensively evaluated in various parts of the world. Previous studies have identified some of the common risk factors to for LBP such as job requiring repetitive heavy lifting, use of jackhammers or machine tools and the operation of motor vehicles (Frymoyer et al., 1983). Motor vehicle drivers are seen particularly at higher risk as they have a higher probability of exposure to other occupational risk factors that possess compounding effects on LBP. Not only are they exposed to whole body vibration (WBV), they are also involved in heavy lifting, manual handling activities (MMH), prolonged sitting and awkward posture. Previous studies have found that occupational exposure to WBV is associated with an increased risk for LBP, sciatic pain and degenerative changes in the spinal system including lumbar intervertebral disc disorders (Bovenzi & Hulshof, 1999a). Occupational vehicle drivers were also reported to have increased frequency of lumbar prolapse (Lings & Leboeuf, 2000).

It is believed that WBV work in combination with other factors for the development of LBP among drivers. The causal relationship between spinal health and WBV must exist, even though its exact nature is not fully known (Government of Alberta, 2010; Seidel, 2005). Vibration at 4-6 Hz frequency gives the most intense effect to the biologic “soft spring” between S-1 and the seats, that triggers sequential muscle nerves firing to induced muscular fatigue (Pope & Hansson, 1991). Muscular fatigue at the back reduces both capacity to dissipate energy and strength. The victim become less able to react further loading especially when they must perform MMH leading to spinal injury. Internal load or forces to the spine give compression to intervertebral discs and disturbs the diffusion between intervertebral discs and surrounding tissues resulting in more rapid disc degeneration.

In a study involving vehicular drivers, prolonged driving for more than 4 hours/day, prolonged sitting in relation to long distance driving over 19,000 miles/year, and duration of employment over five years were identified as the main risk factors of LBP (Gallais & Griffin, 2006). Most of the studies conducted in Asian region found a consistent finding. A study conducted in Hong Kong among bus drivers reported 18% of the respondents have been a bus driver for the past 20 years with long working hours of at least 9.5 hours per shift or a cumulative of 57 hours per week (Szeto & Lam, 2007). Another study in Japan among taxi driver found that increase in prevalence of LBP is positively correlated with increase in total mileage (Funakoshi, Taoda, Tsujimura, & Nishiyama, 2004). A study among taxi drivers in Taiwan found that long hours driving of more than 4 hours per day is associated with increase in prevalence of LBP (Chen, Chang, Chang, & Christiani, 2005). Other potential predictors of LBP are individual and psychosocial characteristics, such as self-perceived job stress and job dissatisfaction (Chen et al., 2005) and mental stress (Miyamoto et al., 2008).

Evaluation of vibration (ISO, 1997) requires that both basic and additional methods of evaluation are reported (ISO, 1997). Studies have shown that in a group of drivers exposed to low accelerating WBV that is below the recommended margin for health guidance, a large proportion of them still reported low back pain (Chen et al., 2004). This phenomenon suggests that the total impact of WBV was probably not captured by the r.m.s (root-mean-square) measurement also known as basic methods, especially in intense oscillatory acceleration (shock, impact, bumps). A measurement method using r.m.q (root-mean-quad) also known as additional methods is more appropriate for this purpose. Hence reporting impact of WBV using various methods inclusive of basic and additional methods with daily and cumulative dose calculation is important. The need of producing a complete exposure data for WBV is slowly being practiced and adapted. Several reports on the extensive evaluation of WBV indicate that researchers prefer to evaluate their effects to development LBP using several methods (Bovenzi, 2009, 2010; Tiemessen, Hulshof, & Frings-Dresen, 2008). Future studies should be focused on WBV load exposure history, because interventions aimed at minimizing their exposure will result in a promising impact in prevention of LBP (Wilder & Pope, 1996).

Furthermore, regulation can be put in place to protect at risk individuals from excessive exposure to WBV. The available regulation namely the ISO Standard and the European Directive proposed the recommended value that able to ascertain an increased risk of the worker when exposed excessively. For instances the European Directive 2002/44/EC-Vibration (European Parliment and the council of European Union, 2002) proposes the recommended value for EAV (Exposure Action Value) and ELV (Exposure Limit Value) whereas the ISO Standard formulated the Health Guidance Caution Zone (HGCZ). The HGCZ classified the WBV exposures into zone that identified those exposed with minimal, moderate or high risks. The guide prescribed from the available regulation certainly help to administer control measures to protect workers from health and safety risks.

In Malaysia, studies on identification of risk factors for occupational LBP have been studied only recently and regulations on WBV and hand transmitted vibration are not well established (Tamrin et al., 2007). Adaptation of regulations from other countries needs caution due to the limited data available for comparison. Data on relationship between WBV and LBP among professional drivers is currently scarce in Malaysia. This is particularly true for their dose effect relationship in this group of people. Hence this study hopes to provide new insights on WBP and LBP to guide policy making.

1.2 Problem Statement and Public Health Significance

The WBV exposure is the product of exposure intensity expressed in acceleration and exposure time (Tiemessen et al., 2008). Prediction of health hazard as impact of WBV, generally assumed dose effect relationship (ISO, 1997). This warrants for equal emphasis given to both acceleration magnitude and duration of exposures in measurement of WBV exposure. Both parameters are required in WBV dose calculation. The calculated daily and cumulative WBV doses serve as indicator to establish dose response relationship, because previous studies found that duration of exposure to WBV is better correlated with LBP than vibration magnitude alone (Bovenzi, 1996). Prevalence of LBP increases with vibration dose (Boshuizen, Bongers, & Hulshof, 1990), therefore increasing vibration dose is a good predictor of lumbar syndrome caused by exposure to vibration (Schwarze, Notbohm, Dupuis, & Hartung, 1998)

Effective prevention strategies are required to better protect workers exposed to WBV. Therefore, it is only appropriate that we seek a better understanding of the risk factors of LBP among professional drivers and identify ways to reduce them (Gallais & Griffin, 2006). WBV exposure has not been proven as the sole contributor to pathogenesis of low back disorders. However, WBV is one of the known risk factor that is measurable and objective assessment could be carried out easily using a widely accepted standard (ISO, 1997). Recognizing that WBV is one of the risk factors of LBP that is modifiable, a lot of focus has been put to study details of its exposure. Even a small excess WBV in risk will result in large number of victims with back pain (Gallais & Griffin, 2006). We hope that implementation of a single intervention to reduce WBV certain risk could probably help reduce the number of people with low back disorders. This study is designed in compliance with the entire quantitative requirement as outline by ISO standard document (ISO, 1997) which to provide a detailed assessment of dose response relationship between WBV exposure and LBP among the study group.

1.3 Rationale of the Study

Based on our reviews, local data on WBV exposure is by and large limited. Available studies are limited to reporting WBV exposures based on daily dose calculation (Aziz, Nuawi, & Mohd Nor, 2014; Rozali et al., 2009). To date, there has not been any studies that further explore dose response pattern of WBV with LBP, except for hand arm vibration syndrome (Su et al., 2013).

Selection of Sabah as area to conduct the study mainly due to the geographical and road conditions that might be different from Peninsular Malaysia. As reported from the other studies the road condition could alter the WBV magnitude hence subsequently exposure level among drivers. To date no study published available that conducted in specific part of Sabah. Apart from that considering the climate of Sabah as in tropical region unfavourable climate conditions can among one of the factor that put strain on the back, shoulder and neck.

Our main concern is to protect our workers, particularly vehicle drivers. However to effectively evaluate the extend of WBV exposures among drivers, we need to at least report data on the daily measure either in A(8) or VDV format to allow comparison with standard limits and to be able to recommend for effective interventions.

Data from some countries are based on routine monitoring of drivers potentially exposed to daily WBV level that is beyond the recommended limit (Lewis & Johnson, 2012). Based on these data, vibration exposures exceeding the permitted values warrant attention and need further evaluation. Hence, the rationale of this study:

1. To gather a complete set of data on exposure to WBV, inclusive of acceleration magnitude expressed in basic and additional methods and total duration of exposures.
2. To generate a comprehensive calculation of WBV exposures data inclusive of daily and cumulative measures which are apparently lacking in our local setting.

3. To identify the extent and severity of exposure to vibrations among drivers in local setting based on dose response pattern as addition to the existing knowledge.

1.4 Research Question and Hypotheses

This study aimed to answer some pertinent questions related to WBV exposure data and the outcome measures of LBP among professional drivers in the state of Sabah. The followings are our research question and related hypothesis;

Research Question:

Is there any difference in WBV exposure in relation to development of LBP among drivers who drive different types of vehicles in the state of Sabah?

P	: Occupational drivers
I(E)	: Whole body vibration
C	: Nil
O	: Occurrence of LBP (symptoms occurred at 12 months prior, 4 weeks prior and post driving)

Research Hypothesis:

1. **Null Hypothesis (H_o):** There is no significant difference between exposure to WBV in different types of vehicles for development of LBP among drivers in Sabah
2. **Alternative Hypothesis (Ha):** There is significant difference between exposure to WBV in different types of vehicles for development of LBP among drivers in Sabah.

1.5 Study Objectives

1.5.1 General Objectives

To determine the dose response relationship between WBV and LBP among drivers in the tropics.

1.5.2 Specific Objectives

1. To describe WBV pattern produced by different type of vehicles in the study population.
2. To determine the extent of WBV exposure among drivers in the study population.
3. To quantitatively describe dose response relationship between WBV exposures and LBP.
4. To conduct review for the work-related WBV exposure among professional drivers, WBV exposure towards human spinal structures and work-related MSD among professional drivers.

1.6 Thesis Contribution

This thesis has two main sections. The first part of this study describes WBV exposure data among different types of vehicles involved in this study. This data will provide a clear picture of the extent of exposure to WBV and how it affects a person's health, particularly development of low back morbidity. Having these data will allow us to evaluate the extent of this issue in our local setting and how we could help design an effective control measure to protect the group at risk.

The second part is to establish the values of WBV dosage that is harmful and to make comparison with available data from different regions of the world. Adaptation of any regulation or directive for control measures from other region have to be exercise with precaution. Effects of WBV to bodily morbidity in different settings may not be similar because findings from previous studies indicate that WBV effect towards human body is influences by multiple factors. Hence, the data from this study is very important to add to the existing collection of data or information available. The readings can gauze to estimate and construct local values to identified and categorized them according to the predicted health risk based on the WBV exposure among our drivers.

CHAPTER 2: LITERATURE REVIEW

2.1 Whole Body Vibration

2.1.1 Definition

Whole Body Vibration (WBV) is defined as a shaking or jolting of the human body through a supporting surface (usually a seat or the floor) when driving or riding on a vehicle or standing on structure attached to a large, powerful, fixed machine which is impacting or vibrating (HSE, 2005a). Vibration exposure can be classified based on its source and the modes they get introduced into the human body. There are two types of vibration exposure that are of interest. First, the segmental vibration, which refers to exposure that is mainly transmitted and concentrated on a specific part of the body – such as the hand, arm, or leg. Second, WBV exposure is when vibration is transmitted throughout all or most of the body (Government of Alberta, 2010).

Mechanical vibration is defined as vibration occurring in a piece of machinery or equipment or in a vehicle as a result of its operation (Griffin et al., 2008). In the case of WBV, mechanical vibration is transmitted into the body through the supporting surfaces namely the feet of standing man, the buttocks of a seated man or the supporting surfaces of a reclining man during a work activity (Burgess & Foster, 2012; Government of Alberta, 2010; Griffin et al., 2008; HSE, 2005a; ISO, 1997).

Professional driver is an occupation that is exposed to WBV at higher magnitude and longer duration of time. Drivers are commonly exposed to WBV in off-road driving, such as farming, construction and quarrying. However, exposure to WBV can occur elsewhere, for example on the road in lorries and trucks, at sea in small fast boats and in the air in some helicopters (Griffin et al., 2008). WBV exposure often comes from a variety of vibration sources, originating from one or more components of a machine, vehicle or surface. These sources can include engines and engine parts, movement of gears and transmissions, rotation of tires, wheels and axles also the movement of the vehicle over irregular surfaces (Government of Alberta, 2010).

The aspect most commonly considered when discussing WBV is the substantially continuous vibration that occurred when driving along a grooved road or if the vehicle has a rough engine. Vehicles such as vans, lorries and buses, which are normally driven on well-maintained public roads, may also expose their drivers to some WBV, but the levels are likely to be relatively low (HSE, 2005b), unless the vehicles do not have effective suspension or are driven over poor road surface (HSE, 2005a). The other aspect is a sudden short duration vibration referred to as a shock or 'jarring' which can occur when a vehicle goes over a single deep hole. In most cases these sudden jolts and jars are unexpected so the driver does not have the warning or the opportunity to prepare for the shock (Burgess & Foster, 2012). WBV is not restricted to seated workers such as drivers, but may also be experienced during standing operations such as standing on a concrete crushing machine (Griffin et al., 2008).

2.1.2 Standard Measurement and Evaluation

The ISO standard document (ISO, 1997), part one (General Requirement) Mechanical Vibration and Shock-Evaluation of human exposure to WBV become the main reference for the measurement and evaluation of WBV. This international document is widely accepted standard for WBV assessment and provides guidelines on how to properly measure and interpret WBV in relation to human health and comfort (Killen & Eger, 2016)

The scope of this document covers the methods for measurement of periodic, random and transient WBV and indicated the principal factors in combination to determine the degree to which vibration exposure is acceptable. The manual identified worker such as those dealing with vehicles (air, land and water), machinery (those used in industry and agriculture) and industrial activities (such as piling and blasting) as target group. This is applicable to motions transmitted to the human body which can interfere with comfort, activities and health. It also defines the principal of preferred methods of mounting transducer or also known as accelerometer for determining the human exposure.

2.1.2.1 Reference Document: International Standard ISO 2631-1(1997)

Vibration is very complex. It contains a wide range of frequencies that occur in several directions and able to change over time (ISO, 1997). Due to its complexity, measurement and evaluation of WBV require a good understanding of specific terminology used in reporting. This document outlines specific requirements that need to be adhered to and be complied upon when reporting a vibration conditions. All the terminologies used in reporting of the WBV are clearly defined in this document.

a) Acceleration

The primary quantity of vibration magnitude is in acceleration. The magnitude of vibration could be expressed as the vibration displacement (in metres), the vibration velocity (in metres per second) or the vibration acceleration (in metres per second per second or m/s^2). Velocity measurements is used to quantify a very low frequencies and low vibration magnitude such as vibrations in the building or ships which is then translated into accelerations. However, most vibration transducers or accelerometer produce an output that is related to acceleration. Their output is dependent on the force acting on a fixed mass within the transducer (for a fixed mass, force and acceleration are directly related). Acceleration has traditionally been used to describe vibration (Griffin et al., 2008). Translational acceleration is expressed in meters per second squared (m/s^2). Values are quoted as root-mean-square (r.m.s) unless stated otherwise.

b) Axes

The direction of vibration operates in accordance with the system of co-ordinates in relation to human body. Three direction of translational that required to be monitor as recommended by the ISO Standard document are the back to chest direction (x axis) or also known as fore and aft, the right to left direction (y axis) also known as lateral and the vertical direction (z axis) (ISO, 1997). All measurement of WBV are reported in relation to these three orthogonal axes.

c) Frequency and weighting factors

Frequency represents the number of times per second the vibrating body moves back and forth. It is expressed as a value in cycles per second, more usually known as hertz (abbreviated to Hz). For WBV, the frequencies of importance range from 0.5Hz to 80Hz. (Griffin et al., 2008). Resonant frequency is defined as the frequency at which an object will freely vibrate after it has been stuck mechanically. In a simple one degree of freedom system, the frequency at which an object will freely vibrate is proportional to the square root of stiffness divided by the mass the object (Pope & Hansson, 1991).

The way vibration affects health, comfort, perception and motion sickness is dependent on the vibration frequency content. Different frequency weighting is required for the different axes of vibration. The risk of damage is not equal for all frequencies. The frequency-weighting is used to represent the likelihood of damage from different frequencies. The weighted acceleration decreases when the frequency increases. For WBV, two different frequency weightings are used. The W*d* weighting applies to the x-axis and y-axis, whereas W*k* weighting applies to the z- axis vibration (ISO, 1997). When considering WBV risks to health, an additional multiplying factor must be applied to the frequency weighted vibration values.

d) Vector Sum

Vector sum or also known as vibration total value are calculated to combine all vibration coming from more than one direction (ISO, 1997). The vibration total value determined from orthogonal coordinates are calculated using the following formula:

$$\mathbf{a_v = (\mathit{k_x}^2 a_{wx}^2 + \mathit{k_y}^2 a_{wy}^2 + \mathit{k_z}^2 a_{wz}^2)^{1/2}} \qquad \mathbf{2\text{-}1}$$

Where a_{wx}, a_{wy}, a_{wz} are the weighted r.m.s acceleration with respect to the orthogonal axes x, y, z respectively and k_x, k_y, k_z are multiplying factors. The use of the vibration total value is recommended for comfort, hence application of multiplying factors depends on the frequency weighting selected. Vector sum has been proposed to be used for evaluation of health and safety risk when there was no observable dominant axis of vibration. When determining the probability of adverse health effect, the frequency weighted r.m.s acceleration with the highest magnitude is used. However there is ambiguity in this application (Killen & Eger, 2016), the standard also propose the usage of vector sum to estimate health risk when two or more axes are comparable.

e) Crest Factor

Crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration signal in r.m.s value (ISO, 1997). The values of the crest factor is used to investigate suitability of evaluation methods. The recommendation stated that the values of crest factor below or equal to nine, indicate that the basic evaluation methods is sufficient. The values of crest factor above nine is an indication that vibration being measured contains an occasional shocks and transient vibration, hence using the basic evaluation alone may underestimate the severity of its effect to human being. In this case, ISO standard recommends the use of the additional evaluation methods of vibration measurement (ISO, 1997).

f) Basic Evaluation

Vibration evaluation in basic evaluation method includes measurement of the weighted root-mean-square (r.m.s) acceleration (ISO, 1997). Weighted r.m.s acceleration is expressed in meters per second squared (m/s^2) for translational vibration. The weighted r.m.s acceleration is calculated in accordance with the following equation or its equivalents in the frequency domain:

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

Where $a_w(t)$ is the weighted acceleration as a function of time in meters per second square (m/s^2) and T is the duration of the measurement.

g) Additional Evaluation

There are two types of additional evaluation methods stated in the ISO standard document (ISO, 1997). The running r.m.s evaluation methods also known as maximum transient vibration value (MTVV) and the fourth power vibration dose method known as vibration dose value (VDV). The running r.m.s method takes into account occasional shocks and transient vibration by use of short integration time constant. The VDV method is widely used as part of the reporting for WBV, hence a more preferred method compared to MTVV. VDV is more sensitive to peaks vibration and quoted using the weighted root-mean-quad (r.m.q) component. It uses fourth power instead of second power of the acceleration time used in basic evaluation. The fourth power vibration dose value (VDV) is expressed in meters per second to the power of 1.75 (m/s$^{1.75}$) and defined as:

$$\mathrm{VDV} = \left\{ \int_0^T [a_w(t)]^4 \, dt \right\}^{\frac{1}{4}} \quad \textbf{2-3}$$

Where the $a_w(t)$ is the instantaneous frequency weighted acceleration and T is the duration of measurement.

If vibration exposure consists of two or more periods of different magnitudes, the vibration dose value for the total exposure should be calculated from the fourth root of the sum of the fourth power of individual vibration dose values:

$$\mathrm{VDV_{total}} = \left(\sum_i \mathrm{VDV}_i^{\,4} \right)^{\frac{1}{4}} \qquad \textbf{2-4}$$

2.1.2.2 Instrument: Accelerometer

The instrument used to measure the vibration acceleration is known as accelerometer or transducer. WBV exposure is defined as the vibration measured at the interfaces between the machine and the operator, mainly at the driver seat (Seidel, 2005). The placement of the accelerometer clearly defined where the transducer shall be located so as to indicate the vibration at the interface between the human body and the source of its vibration (ISO, 1997). The placement of transducer for seated position follows three principles as described in the manual: the supporting seat surface, the seat back and the feet.

2.1.3 Review on epidemiological studies of work related WBV exposures among professional drivers

2.1.3.1 Method

Occupational related exposure to WBV related is one of the modifiable risk factors commonly linked with the development of low back pain (LBP) among professional drivers.

For the purpose of this study we conducted an extensive review of studies among professional drivers to ascertain the source of WBV in term of types of vehicles, method of vibration measurement, exposure assessment and factors that influence the acceleration magnitude. Original articles were obtained through a search in database PubMed, Science Direct, Springer Open and Google Scholar. Electronic searchers used various combinations of the following keywords and phrases: assessment of WBV, measurement of WBV, LBP, professional drivers and dose response. The original articles related to monitoring and evaluation of WBV exposures among professional drivers were retained for use. Each study was analysed and summarized in tabular form under the following headings: (i) author, year of publication, country of origin; (ii) study design; (iii) study population and types of vehicle; (iv) methods of WBV measurement in terms of standard reference, type of equipment, number of samples taken for monitoring and duration of monitoring; (v) exposures assessment, including acceleration magnitude, duration of exposures and dose calculation; (vi) factors influencing WBV and (vii) key outcomes.

2.1.3.2 Results

Thirty five original articles were identified (Aziz et al., 2014; Boshuizen et al., 1990; Bovenzi, 1996, 2009, 2010; Bovenzi et al., 2006a; Bovenzi & Betta, 1994; Bovenzi & Zadini, 1992; Dundurs, 2001; Eger, Stevenson, Boileau, & Salmoni, 2008; Funakoshi et al., 2004; Futatsuka et al., 1998; Harris, Cripton, & Teschke, 2012; Hoy et al., 2005; Johanning, Fischer, Christ, Göres, & Landsbergis, 2002; Johnson, Dennerlein, Ramirez, Arias, & Rodríguez, 2015; Kim et al., 2015; Lewis & Johnson, 2012; Lines, Stiles, & Whyte, 1994; Marin et al., 2016; Mayton, Jobes, & Gallagher, 2014; Nishiyama, Taoda, & Kitahara, 1998; Okunribido, Magnusson, & Pope, 2006; Okunribido, Magnusson, & Pope, 2006; Okunribido, Shimbles, Magnusson, & Pope, 2007a; Palmer et al., 2003; Palmer, Griffin, Bendall, Pannett, & Coggon, 2000; Raffler, Hermanns, Sayn, Göres, Ellegast, Rissler, et al., 2010; Börje Rehn, Nilsson, Olofsson, & Lundström, 2005; Rozali et al., 2009; Schwarze et al., 1998; Tamrin et al., 2007; Thamsuwan, Blood, Ching, Boyle, & Johnson, 2013; Tiemessen et al., 2008; Paschold, 2015). A presentation of the study characteristics of the 35 reports were presented in Table 2.5. Majority of the articles described as cross sectional study design however from the 23 identified using cross sectional design about three studies did not clearly describe in their report. Another 10 studies claimed to use the longitudinal or cohort design but only five studies with clear description and another five based on assumption. The remaining two studies clearly define using case control (Harris et al., 2012) and randomized control trial (Kim et al., 2015). Please refer Table 2.1 that summarized the study design involved.

Table 2.1: Study Design in 35 Selected Studies

First Author	Cross sectional with clear description		Longitudinal/cohort with clear description		Other design with Clear description	
	Yes	No	Yes	No	Yes	No
Boshuizen				No		
Bovenzi				No		
Bovenzi				No		
Lines	Yes					
Bovenzi				No		
Futatsuka		No				
Nishiyama				No		
Schwarze			Yes			
Palmer	Yes					
Dundurs	Yes					
Johanning	Yes					
Palmer	Yes					
Funakoshi	Yes					
Hoy	Yes					
Rehn	Yes					
Bovenzi			Yes			
Okunribido	Yes					
Okunribido	Yes					
Okunribido	Yes					
Tamrin	Yes					
Eger	Yes					
Tiemessen			Yes			
Rozali	Yes					
Bovenzi			Yes			
Bovenzi			Yes			
Raffler		No				
Lewis		No				
Harris					Yes (case control)	
Thamsuwan	Yes					
Mayton	Yes					
Paschold	Yes					
Johnson	Yes				Yes (randomized control trial)	
Kim						
Marin	Yes					
Aziz	Yes					

a) Study population and type of vehicles

The method of selection of study population were clearly described in most of the articles. Generally, the study population involved with the studies in this review mostly come from a predetermined group of drivers who work for certain private companies, except for two studies (Palmer et al., 2003; Palmer et al., 2000) which conducted their study among random sample from community and another study among resident of British Columbia (Harris et al., 2012). Finding as summarized in Table 2.2.

The selection method for respondents from a predetermined group of drivers were mainly based on convenient sampling i.e. availability of the respondents during data collection and voluntary participation. Apart from that the researcher from these 33 studies using approach to engage the top-level managements of the selected companies or through association or union worker to encourage participation from drivers.

There were wide variety of vehicles involved in the studies, however most it classified under heavy vehicles such as trucks and tractors. Apart from that the passengers' vehicle such as bus and taxi were also studied quite extensively. Please refer Table 2.2.

Table 2.2: Study Population and Types of Vehicles Involved in 35 Studies

First Author	Study Population Predetermined Group		Types of vehicles
	Yes	No	
Boshuizen	Yes		Agricultural tractor
Bovenzi	Yes		Bus
Bovenzi	Yes		Tractor
Lines	Yes		Agricultural tractor
Bovenzi	Yes		Bus, tractor
Futatsuka	Yes		Agricultural machinery
Nishiyama	Yes		Tractor
Schwarze	Yes		Forklift truck, truck, earth moving machine
Palmer		No	Mixture of multiple types of vehicles
Dundurs	Yes		Trolley bus
Johanning	Yes		Locomotives
Palmer		No	Mixture of multiple types of vehicles
Funakoshi	Yes		Taxi
Hoy	Yes		Forklift truck
Rehn	Yes		Snow groomers, snowmobiles, forwarders
Bovenzi	Yes		Mixture of multiple types of vehicles
Okunribido	Yes		Mixture of multiple types of vehicles
Okunribido	Yes		Van, articulated truck, tipper truck
Okunribido	Yes		Mini bus, double decker bus
Tamrin	Yes		Bus
Eger	Yes		Load haul dump mining
Tiemessen	Yes		Mixture of multiple types of vehicles
Rozali	Yes		Tracked and wheeled army vehicles
Bovenzi	Yes		Mixture of multiple types of vehicles
Bovenzi	Yes		Mixture of multiple types of vehicles
Raffler	Yes		Mixture of multiple types of vehicles
Lewis	Yes		Bus
Harris		No	Mixture of multiple types of vehicles
Thamsuwan	Yes		Bus
Mayton	Yes		Haul truck, front end wheel loader
Paschold	Yes		Solid waste collection truck
Johnson	Yes		Heavy equipment vehicles
Kim	Yes		Long haul truck
Marin	Yes		Heavy equipment vehicles
Aziz	Yes		Three tone truck

About 20 studies clearly defined the inclusion criteria used for selection of respondents. There are three characters that frequently taken into consideration which is age, gender and working duration with another additional parameter decided by the researcher. Work duration become the main consideration with six studies requires their drivers to have minimum one year experience (Bovenzi, 2006, 2009, 2010; Okunribido et al., 2006; Okunribido et al., 2007a; Paschold, 2015) and eight studies put stringent requirement in their selection criteria only took consideration of those who had five years and above of experience (Bovenzi, 1996; Bovenzi & Betta, 1994; Bovenzi & Zadini, 1992; Futatsuka et al., 1998; Johanning et al., 2002; Marin et al., 2016; Okunribido et al., 2006; Raffler, Hermanns, Sayn, Göres, Ellegast, Rissler, et al., 2010; Schwarze et al., 1998). Only one study reported to have used universal sampling with minimum three months experienced (Rozali et al., 2009). Age of respondents also play major roles as researcher usually aimed for participation from certain age with six studies clearly mentioned the age limit (Bovenzi & Betta, 1994; Bovenzi & Zadini, 1992; Palmer et al., 2003; Palmer et al., 2000; Schwarze et al., 1998). Finding summarize in Table 2.3. Another four of the studies reported on specific criteria for selection i.e. triplet matched with age and year of driving (Nishiyama et al., 1998), exposure to WBV quantify as one-hour in a week (Tiemessen et al., 2008), drivers with no medical complaint (Raffler, Hermanns, Sayn, Göres, Ellegast, & Rissler, 2010) and the remaining one study with involvement of only driver as their respondents (Dundurs, 2001). Seven studies reported on the gender requirement as inclusion criteria with five studies include male drivers only (Bovenzi, 2009, 2010; Bovenzi et al., 2006b; Bovenzi & Betta, 1994; Tiemessen et al., 2008), however two of the studies take consideration of both gender (Palmer et al., 2003; Palmer et al., 2000). Overall 10 studies reported a response rate ranging between 55.2% and 97.0% and the remaining 25 studies did not mention clearly in the report.

Table 2.3: Inclusion Criteria for 20 Selected Studies

First Author	Inclusion Criteria			
	Age (years)	Gender	Work duration (years)	Other
Bovenzi	26-55	-	5	-
Bovenzi	25-65	-	5	-
Bovenzi	26-55(Bus) 25-65(Tractor)	Male	5	-
Nishiyama	-	-	-	Triplets matched with age and year of driving
Schwarze	30-40	-	> 10	-
Palmer	Working age	Male/Female	-	-
Dundurs	-	-	-	Only one drivers selected
Johanning	-	-	10-30	-
Palmer	Working age	Male/Female	-	-
Bovenzi	-	Male	≥ 1	-
Okunribido	-	-	≥ 1	-
Okunribido	-	-	5	-
Okunribido	-	-	≥ 1	-
Tiemessen	-	Male	-	Exposure to WBV, one hour per week
Rozali	-	-	> 3 months	
Bovenzi	-	Male	≥ 1	-
Bovenzi	-	Male	≥ 1	-
Raffler	-	-	5	No medical complaints
Paschold	-	-	≥ 1	-
Marin	-	-	14	-

b) Measurement of WBV

For the measurement of WBV exposures, the most common standard adapted by the studies was the ISO 2631-1. However some studies adapted the British Standard 6841 (Lines et al., 1994; Palmer et al., 2003; Palmer et al., 2000). Three of the studies reported to have used both the ISO 2631-1 and ISO 2631-5 as their reference (Eger et al., 2008; Johnson et al., 2015; Thamsuwan et al., 2013). The types of instrument utilize to measure vibration were the triaxial seat pad accelerometer that come from different brand and model. However, all of them claimed to comply with the requirements of the ISO standard. Measurements to determine the magnitude of acceleration usually involve representative number of vehicles conducted at driver's seat surface. However, four studies in this did not performed measurement of WBV exposure, instead data were collected from estimates of values from previous readings (Boshuizen et al., 1990) or from the database of machinery vibration registry (Palmer et al., 2003; Palmer et al., 2000; Schwarze et al., 1998). Some studies performed measurements on the vehicles' floor for the purpose of comparison with readings taken from the seat interface (Johanning et al., 2002; Johnson et al., 2015; Kim et al., 2015; Lewis & Johnson, 2012; Lines et al., 1994; Mayton et al., 2014; Thamsuwan et al., 2013). There was no fixed duration of measurement recorded. The duration of measurements was decided by the individual researchers. Furthermore, not all studies reported the duration of measurement used in their study. Among the studies that reported the duration of measurement used in their studies, the duration ranged from five minutes to continuous monitoring for two to three shifts with total duration of 99 hours. Measurements of WBV were mostly conducted base on the actual daily routines of the drivers. However, some researcher decided that the drivers use a common route to ensure a standardize measurement and to allow for measurements in different road surfaces (Aziz et al., 2014; Dundurs, 2001; Futatsuka et al., 1998; Lewis & Johnson, 2012; Nishiyama et al., 1998; Okunribido et al., 2007a; Rozali et al., 2009; Thamsuwan et al., 2013).

c) Assessment of WBV exposures

The ISO 2631-1 standard document is widely accepted as reference for most the studies hence it is expected that reporting on the magnitude of acceleration would strictly comply with the requirements stipulated in this document. Most of the studies reported the magnitude of WBV using frequency weighted r.m.s accelerations (ms^{-2}) in three axes namely x, y and z axis and the vector sums value. However, some of the studies reported additional parameters such as crest factor (CF), frequency weighted r.m.q acceleration or known as VDV ($ms^{-1.75}$) and MTVV.

Assessment of WBV exposure not only requires reporting on acceleration magnitude but also duration of exposures. Both measures are needed to calculate the vibration dosages. Acceleration magnitude calculation can adapt the vector sums value and/or the predominant axis. In this review, the two most common methods used to assess the duration of exposure were using a self-administered questionnaire or a structured interview. The most common data collected were the estimation of daily exposures and total years of employment as professional drivers. However, some researchers collected information from company record (Funakoshi et al., 2004) or daily exposure data determined by a technical advisory committee (Eger et al., 2008). Some of the studies did not report on the duration of exposure, therefore did not proceed to calculate the vibration doses. For Studies that performed the dose calculation, the daily dose were calculated in terms of A(8) and VDV and cumulative vibration dosages. The acceleration magnitude either the predominant axis or the vector sums were used for calculation of the dose exposures.

d) Factors influenced WBV

Most of the studies identified factors that could influence the observed value of WBV measured in their studies. The most common factors reported by the studies were the types of the road surfaces, vehicles model, year of manufacturing, driving speed, duration of vehicles in service and the condition and design of the car seat. Most of the researchers tried to control for the identified factors. Some of the strategies to control for these factors were to fix the test route in such a way that allowed for measurements on different road surfaces or setting up the vehicles with the intended conditions i.e. vehicles in used with or without loads (Dundurs, 2001). Some studies conducted measurements both while the vehicles were moving and idling (Okunribido et al., 2007a).

e) Key reported outcomes

About 18 studies in this review explored on the dose response effect of WBV with ten reported a significant dose response relationship between WBV exposures and the development of adverse health effects (Boshuizen et al., 1990; Bovenzi, 1996, 2009, 2010; Bovenzi et al., 2006b; Bovenzi & Betta, 1994; Bovenzi & Zadini, 1992; Lines et al., 1994; Schwarze et al., 1998; Tiemessen et al., 2008). Three studies were not able to elicit any significant associations (Okunribido et al., 2006; Palmer et al., 2003; Palmer et al., 2000) . Two of the studies did not explore the possibility of dose response relationships because their main objectives were to assessed the impact of the seat design to WBV exposure (Dundurs, 2001; Nishiyama et al., 1998), one study to evaluate the difference of measurement conducted on the seat interface in comparison to floor interface (Thamsuwan et al., 2013), one study each to evaluate the impact of different speed and load capacity of the vehicles (Mayton et al., 2014) and impact observed for the different road surfaces (Aziz et al., 2014). Four of the studies confined their reports on the impact of acceleration magnitude (Funakoshi et al., 2004; Futatsuka et al., 1998; Johanning et al., 2002; Tamrin et al., 2007) and another five studies did not clearly define the involvement of WBV dose exposures (Hoy et al., 2005; Okunribido et al., 2006, 2007a; Raffler, Hermanns, Sayn, Göres, Ellegast, & Rissler, 2010; Börje Rehn et al., 2005). Please refer Table 2.4.

About 15 of the studies included in this review reported that the WBV exposures exceeded the recommendation either using the limit or action values as proposed by European Guidelines, ISO Health Guidance Caution Zone (HGCZ) and British Standard (BS). Four studies reported an acceptable range of WBV exposure when compared to recommendation level (Okunribido et al., 2006; Tamrin et al., 2007; Hoy et al., 2005; Rozali et al., 2009). One of the study reported adverse health impact observed despite lower exposures to WBV comparatively to the limits as prescribed in ISO 2631-1

(Bovenzi & Zadini, 1992). Consequently, one study proposed that the European Guidelines appeared to be more realistic to prevent the long term health effect than the exposure limit by ISO standard (Bovenzi & Betta, 1994).

Critical appraisal on the methods of assessment used by researcher in this review to measure dose exposures revealed that the alternative measures of r.m.q acceleration were more predictive for the occurrence of the adverse health impacts (Bovenzi, 2009, 2010). Furthermore, utilization of the predominant axis for calculation of vibration dosages appeared to give a lower value than the prescribe recommended level as opposed to vector sums value which gave a consistently higher values (Johnson et al., 2015; Kim et al., 2015; Marin et al., 2016).

Table 2.4: Key Reported Outcomes for 35 Selected Studies

First Author	Key reported outcomes				
	Evaluation on dose response		Assessment based on standard reference		Other findings
	Yes	No	Above	Below	
Boshuizen	Yes	-	-	-	-
Bovenzi	Yes	-	-	Below[a]	-
Bovenzi	Yes	-	-	-	Proposed EU directive more adequate for prevention in long term in comparison to ISO 2631-1
Lines	Yes	-	Above[a]	-	High CF
Bovenzi	Yes	-	-	-	-
Futatsuka	Yes	-	Above	-	-
Nishiyama	-	No	-	-	Air suspension model reduce LBP rather than steel suspension
Schwarze	Yes	-	-	-	Proposed limit value on lifelong vibration dose (0.6 m/s^2)
Palmer	Yes	-	Above[b]	-	-
Dundurs	-	No	-	-	Seat vibration differ for old and new model
Johanning	Yes	-	-	-	Locomotives rides relatively had high shock content
Palmer	Yes	-	-	-	Excess of LBP and sciatica with exposure with WBV but not consistent relation with dose
Funakoshi	Yes	-	Above[a]	-	Recommended shortening of working hour and taking rest

Table 2.4: continued

First Author	Key reported outcomes				
	Evaluation on dose response		Assessment based on standard reference		Other findings
	Yes	No	Above	Below	
Hoy	?	-	Above[a] (z-axis)	Below[a] (x & y-axis)	-
Rehn	?	-	Above[a,c]	-	Dominant vibration direction varies depending on machine type
Bovenzi	Yes	-	-	-	LBP significantly increase with cumulative vibration dose, not significant with daily dose
Okunribido	Yes	-	-	-	Significant liner dose response for posture and MMH
Okunribido	?	-	-	-	Travel on cobble produce high CF (> 9) and VDV (>15)
Okunribido	?	-	Above[c] (vector sum)	-	Single and double decker produce high CF (> 9) and VDV (>15) during travelling on cobble
Tamrin	Yes	-	-	Below	r.m.s associate with low risk of developing LBP
Eger	Yes	-	Above[a]	-	-
Tiemessen	Yes	-	-	-	Exposure duration main instigator to reveal the dose response
Rozali	Yes	-	Above[c] (EAV)	Below[c] (ELV)	WBV at x-axis as significant risk for LBP
Bovenzi	Yes	-	-	-	Measure of exposure duration (daily/lifetime) provide good indication for LBP
Bovenzi	Yes	-	-	-	Daily exposure to WBV provide good prediction of LBP with alternative measure VDV gave better predication then A(8)
Raffler	?	-	-	-	Combination of WBV and posture exposures exhibited highest workload
Lewis	Yes	-	Above[c]	-	Road types had significant effect on vibration
Harris	Yes	-	-	-	Second power dose metric correlate with total duration of exposure
Thamsuwan	-	No	-	-	Seat attenuate 10% of the floor transmitted vibration
Mayton	-	No	Above[a]	-	Increased in speed of vehicles showed increased vibration recorded
Paschold	Yes	-	Above[a] (EAV)	Below[a] (ELV)	The exposure level suggests the presence of potential health risks

Table 2.4: continued

First Author	Key reported outcomes				
	Evaluation on dose response		Assessment based on standard reference		Other findings
	Yes	No	Above	Below	
Johnson	Yes	-	Above[a,c] (vector sum)	Below[a,c] (dominant axis)	-
Kim	Yes	-	Above[c] (vector sum)	-	VDV values on seat were 29% to 32% higher than floor measurement
Marin	Yes	-	Above[a]	-	High level of exposure for continuous & impulsive WBV exposure
Aziz	-	No	-	-	High road exhibit higher VDV variation

[a] ISO 2631-1, [b] British Standard, [c] European Directive, [d] ISO 2631-5
? Not clearly define

2.1.3.3 Discussions

It is an undeniable fact that certain group of occupational drivers are targets to conduct studies related to assessing the health impact of WBV. This is because drivers appear to be particularly at risk of exposures to vibrations magnitude beyond the recommended limit by the ISO standard (Wilder & Pope, 1996) . A predetermined group of drivers are commonly identified as they are suspected to be exposed with severe WBV i.e. operating heavy vehicles or machinery. An extensive review by Bovenzi & Hulshof (Bovenzi & Hulshof, 1999b) using the meta-analysis of cross sectional and cohort studies showed that occupational exposure to WBV is associated with an increased risk for LBP, sciatica pain and degenerative changes in the spinal system including lumbar intervertebral disc disorders. Cohort study design especially a prospective approach to data collection is the preferred study design, to establish exposure-response relationships and allows development of hypothesis for disease etiology (Magnusson, Pope, Hulshof, & Bovenzi, 1998). However due to time constrains and limited budget, application of cross-sectional design is inevitable. Cross sectional design prone to limitations which may lead to insufficient evidence to permit firm conclusion on clear dose response relationship between WBV exposures and adverse health impact (Bovenzi & Hulshof, 1999b; Hulshof & Zanten, 1987). Another aspect that need extra attention for the assessment of adverse impact of WBV is that exposure data must be carefully measured in order to ensure its validity. This can be achieved by having daily dose measurement and exposure measurement done in a serial manner (Lings & LeboeufYde, 2000).

a) WBV exposures among professional drivers

The two standards that are commonly used to determine the probability of adverse health effects for workers in seated position when exposed to WBV include the ISO 2631-1 and ISO 2631-5 (Killen & Eger, 2016). For easy comparison of data adaptation of the known existing standard is mandatory. Each standard has their own limitation and caution must be exercised when interpreting the adverse health risks within the scope of the selected standard.

The key requirement while assessing and evaluating the risks contributed by WBV at workplace is the routine measurement of WBV exposures. Vibration exposure occurs when a vibrating object, such as a machine, tool or surface, transmits vibration energy to a person's body. For this to occur, a part of the person's body must either be in direct contact with the vibrating object, or another object that is itself making contact with the vibrating object (Government of Alberta, 2010). How the body responds to WBV depends on the frequency of the vibration, the acceleration of the vibration and the length of exposure (Government of Alberta, 2010). Hence, vibration exposure is the level of vibration received by a person (from the vehicles, machine or sources) over a period of time (Scarlett, Price, Semple, & Styner, 2005).

To determine WBV exposure, the first step that need to be done is to evaluate the risk by performing the basic risk assessment (Griffin et al., 2008; HSE, 2005a, 2005b). In the basic assessment, the person at risk need to be identified and we need to understand their daily activities. This will help to determine the exact duration of exposure to WBV at work and what types of vehicles or machinery are operated by the worker. For drivers, the common activities that may lead to vibration exposure are operating different class of a vehicles. Thus, steps taken during risk assessment helps estimate the worker's daily exposure to the risks factor being studied. Both level of exposure and duration of exposure are taken as the estimated values for a daily exposure. In either way the values represent part of a work day or task, thus the results have to be calculated to and extrapolated to represent the eight hours vibration exposure values (Marjanen, 2006).

Assessment of the entire exposure, be it the magnitude or the duration can only achieve by adapting the estimates values with specific precautions. It is almost impossible to measure the entire vibration exposure for all respondents and for their entire working period. It is quite expected that vibration exposure in relation to variability in terms of daily exposure and changes in the types of vehicles operated over the years might not possible to capture and these may compromise the accuracy of data. In actual fact, these are the main challenges faced by researcher in assessing WBV exposure as the evaluation and assessment can be complicated (Griffin et al., 2008).

There are various sources to capture WBV acceleration data. Acceleration magnitude can be collected from data from the manufactures and standardize technical report, good practice guidelines or from data banks. The Machinery Directive originated from European region requires manufacturers, importers and suppliers of machines to provide information on risks from vibration, and values of WBV emissions of mobile machinery. This vibration emission information should be provided in the information or instruction documents that come with machines (Griffin et al., 2008; HSE, 2005b). These sources of published information can be used to estimate the potential vibration exposure experienced by workers (Government of Alberta, 2010). However, direct measurements are often a necessity (Donati et al., 2008) and field measurement of WBV can be challenging (Salmoni, Cann, Gillin, & Eger, 2008). Direct measurement of WBV does involved high coast and technician must be equipped with knowledge and competency on how to perform the tasks. Direct monitoring of vibration being measured undertakes to quantify the level of vibration to which workers are exposed (Chen et al., 2003). As a common practice, measurement of WBV are conducted among the representative vehicles or machinery. However, to ensure a more genuine and specific WBV exposure at individual level, options are available to conduct field measurement to all drivers using the current types of vehicles being operated. Furthermore factors such as driving style and body size could vary and therefore potentially affect exposure (Salmoni et al., 2008). Objective measurement of WBV conducted during actual work performance allows for capture of a clearer picture of working conditions. It would be ideal to visit the measurement site prior to testing so that work can be observed and the conditions affecting measurement assessed (Salmoni et al., 2008) There are many factors identified at work that might influences the variation of the data being measured such as primary average driving speed (average driving speed increased, measured vertical acceleration increased in quadratic linear manner) and other predictors include automobile manufacturer, engine size, body weight, age, use of cushion and traffic period (Chen et al., 2003). High exposures could occur where vehicles designed for smooth surfaces are driven on poor surfaces, poor operating or driving technique (HSE, 2005a). Other work environment factors such as road surfaces does influence the acceleration magnitude (Aziz et al., 2014).

Measurements only occur at certain time. The standards do not give specific guidance on the exact minimum or maximum measurement time length. However, they clearly indicate that the duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed (ISO, 1997). In most cases, the longer the time sampling interval the better, however the practical considerations of work often make it difficult to achieve lengthy time sampling periods (Salmoni et al., 2008).

Assessments of duration of exposure based on the estimated daily exposure are done according to daily work schedule. Working day means a daily working period, irrespective of the time of day when it begins or ends, and of whether it begins or ends on the same calendar day (HSE, 2005b). The employee being exposed to vibration is a reference to the exposure of that employee to mechanical vibration arising out of or in connection with his work (HSE, 2005b). However, it is very difficult to assess a typical workday in terms of driving time (Salmoni et al., 2008). Other issues such as limited time to learn the work environment before testing, poor control over the test setting, limited time of testing, poor cooperation at the test site and lack of knowledge about vibration by health and safety personnel at the companies are some of the issues that make testing in the field is challenging (Salmoni et al., 2008).

Assessment of exposure duration needs careful consideration of the workers work pattern. Exposure towards whole body vibration begins when they start operating their vehicles, not the overall time spent on working day duration. The exposure duration refers only to the time during which the body is actually exposed to vibration (Griffin et al., 2008). The typical daily operating hours of the vehicles used for estimation of the driver's daily vibration exposure and later the estimate values are utilized to formulate the total hours of exposure for the entire working years. This is the most common methods adapted as total hours of exposure is needed for the calculation of the of cumulative dose exposure for WBV. The information on the duration of exposure during daily working schedule can be obtained via several methods (i.e. use of questionnaire via face to face interview, self-reported and direct observation by researcher). However, each method has their own strengths and weakness. Exposure time data captured from face to face interview tend to be higher than data from direct observation, however they are more reliable than data from self-reported questionnaire (McCallig, Paddan, Van Lente, Moore, & Coggins, 2010)

In the exposure duration, another decision should be made on what a minimum working duration in an industry that makes a person exposed to WBV. Some researchers used the minimal exposure duration required for recognition as occupational related disease varies from one years (provided the daily exposure above $1m/s^2$) to ten years (Hulshof, Van Der Laan, Braam, & Verbeek, 2002). For professional drivers, researchers used one year for the minimum length of service as basic criterion for inclusion (Bovenzi, 2009; Bovenzi et al., 2006a). Some researchers proposed that minimum exposure toward WBV should be based on per week quantification (Tiemessen et al., 2008). These illustrate the need to set the minimum exposure duration as inclusion criteria for selection of a respondent to participate in this study.

b) Calculation of WBV Exposure

WBV doses are calculated based on combination of the frequency weighted acceleration magnitude and the duration of exposure. As required by ISO 2631-1, 1997 (ISO, 1997), level of exposure should be calculated based on the frequency weighting.

There are three axes that need to be evaluated, hence in each vibration axis a frequency-weighted root-mean-square or root-mean-quad average acceleration is measured and reported as a_{wx}, a_{wy} and a_{wz}. Since the risk of damage is not equal in all axes, a multiplying factor is applied to the frequency-weighted vibration values. The acceleration values for the two lateral axes (x and y) are multiplied by 1.4, whereas for the vertical (z axis) they are multiplied by 1.0. In the case of WBV, the equivalent acceleration is obtained from the highest of three orthogonal axes' values ($1.4a_{wx}$ $1.4a_{wy}$ or a_{wz}) that are used for the exposure assessment. However, the vector sum or also known as vibrations total value can be utilized. The vector sum may be used when vibrations in two or more axes are comparable and one value (a_v) is desired to describe the overall exposure (Johanning et al., 2002). The combined motions of all three axes could be greater than any one component and could possibly affect vehicle driver performance, hence for predicting human health risk, overall weighted total acceleration may be used to find the resultant force (Dundurs, 2001). Furthermore the vector sum value (a_v) has been shown in epidemiological study to be suitable for quantification of vibrational exposure that may lead to low back pain (Raffler, Hermanns, Sayn, Göres, Ellegast, & Rissler, 2010).

The two most common doses calculations observed from review of epidemiological studies are the daily dose and cumulative dose. Daily exposure means the quantity of mechanical vibration to which a worker is exposed to during a working day, normalized to an 8-hour reference period, which takes account of the magnitude and duration of the vibration (HSE, 2005b). Daily vibration exposure is expressed in terms of either equivalent acceleration over an 8-hours reference period [A(8), root-mean-square (r.m.s) method] or vibration dose value [VDV, root-mean-quad (r.m.q) method]. For the determination of daily dose, it is not necessary to measure over eight hours. However, it is sufficient to make short-term measurements during representative work steps. Subsequently, the results are normalized to eight hours. The formula for calculation of the daily dose are adapted from previous studies (Bovenzi, 2009, 2010; Tiemessen et al., 2008). The formula for daily dose exposure are shown below:

$$\mathbf{A(8) = [\ (h/8) \times (a_{ws})^2\ ]^{1/2}\ (ms^{-2})} \qquad \mathbf{2\text{-}5}$$

$$\mathbf{VDV= a_{wq} \times (h \times 60 \times 60\ )^{1/4}\ (ms^{-1.75})} \qquad \mathbf{2\text{-}6}$$

Where a_{ws} is the weighted acceleration using r.m.s and a_{wq} is the weighted acceleration using r.m.q, h is the total hours of exposure per day.

Cumulative WBV dose is calculated by combining the duration of exposure and whole body vibration magnitude according to the time dependency proposed from previous published paper (Bovenzi, 2009; Tiemessen et al., 2008). Cumulative dose is evaluated and reported using the acceleration magnitude (a_w) expressed in r.m.s and r.m.q respectively. The formula for calculation of cumulative dosages is shown below:

$$\textbf{Cumulative Dose} = \sum[a_w^m t] \qquad \textbf{2-7}$$

Calculation of cumulative dosages, considering the relative important of frequency-weighted acceleration a_w and the total exposure duration, t depends on the value of m. By assigning value of one to m gives equal importance to the vibration magnitude a_w and the exposure duration t, whereas assigning a value of two or four to m increases the importance of the vibration magnitude a relative to that of exposure duration, t. With $m = 0$ the dose takes no account on vibration magnitude. The values of $m = 0, 1, 2$ and 4 assigned to be calculated for cumulative WBV for the drivers (Bovenzi, 2009).

2.1.3.4 Conclusions

In conclusions, study conducted among professional drivers addressing the WBV exposures commonly adapted the ISO 2631-1 standard as reference. Hence the measurement and assessment were strictly confined to the requirement of the standard. They are many possible factors that can influenced the WBV exposure mainly the conditions and types of the vehicles, road surfaces and speed.

Table 2.5: Summary of Study Characteristics; Epidemiological Studies of WBV Exposures Among Professional Drivers

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure assessment			Factors Influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Boshuizen et al/ 1990/ Netherlands	Retrospective cohort	Worker employed by 2 company year 1975 [n=577, RR 79%] & (Agricultural tractor)	ISO 2631-1	NA	NA	NA	Vector sums r.m.s taken from previous measured data in 1985	*Postal Questionnaire* -period of driving specified vehicles (weeks/years & hours/day)	Vibration dose: $\sum a_i^2 t_i$ Vibration Dose Value (VDV): $\sum a_i^4 t_i$	Road surface	Prevalence of LBP ↑ with vibration dose (number of driving years: not all statistically significant)
Bovenzi et al/ 1992/ Italy	Retrospective cohort	Male drivers of municipal company since 1980, n=301, 71% RR (n=234) -Inclusion: 26-55 years old, > 5 years in service & (Urban bus)	ISO 2631-1 (1985)	Triaxial seat accelerometer , B&K 4322, Denmark *seat pan & seat back	Representative sample of vehicles driven past 20 years (n=6) during actual driving condition	15-30 minutes	Frequency weighted acceleration in x,y & z direction (seat pan) r.m.s, x-axis, (seat back) r.m.s z-axis	*Postal Questionnaire* -total driving experience (years), -periods of driving per bus	-Equivalent vibration magnitude: $[\sum(a_{zi}^2 t_i)]^{0.5}$ -Total vibration dose: $(\sum a_{zi}^2 t_i)$ years m^2/s^4 -Duration of exposure: total years in service	Vehicles Model (old vs new)	-LBP ↑ with WBV (total vibration dose, vibration magnitude, duration of exposures) -LBP occurred at WBV level lower than limits (ISO 2631-1)
Bovenzi & Betta/ 1994/ Italy	Retrospective cohort	Male tractor drivers employed in rural district since 1981, (n=1155), RR 91.2%, volunteer participation invitation via mail & follow up via phone call -Inclusion: 25-65yo, > 5 years in service & (Tractor)	ISO 2631-1 (1985)	Triaxial accelerometer *seat pan	Representative sample of vehicles driven past 10 years (n=53) During actual operating condition	NA	Frequency weighted acceleration (a_{wx}, a_{wy} & a_{wz}) r.m.s, vector sum	*Questionnaire (Interview)* -total driving experience in years -types of tractor driven & period of driving per tractor	Total vibration dose: $\sum a_i^2 t_i$ (years m^2/s^4)	Model & manufacturing of tractor	-Low back disorders significantly associated with vibration dose & postural load -European Directive proposal more adequate to prevent long term health effect than the exposure limit by ISO 2631-1
Lines J et al/ 1995/ UK	Cross sectional	Agricultural tractor divided into 13 driving tasks group (n=60) & (Agricultural tractor)	BS 6841 & ISO 2631, (1985)	Triaxial accelerometer (Brueal & Kjaer) *driver's seat /floor	9 measurements on three types of vehicles During actual normal duties	20 min	Frequency weighted acceleration (x, y & z) r.m.s & r.m.q	*Self-administered Questionnaire* -estimated driving per day in n=60 driving daily data	Daily dose	Road surface, tractor size, driving speed	-Tractor driver exposed to high level of WBV and high peak acceleration -majority of tasks exceeded the level of ISO especially cultivation, haymaking & transport -CF on driver's seat can be very high

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Bovenzi/ 1996/ Italy	Retrospective cohort	Male drivers employed in 1980 (bus): n=234, 1981 (tractor): n=1155 -Inclusion: 26-55 years old (bus) & 25-65yr old (tractor) with > 5year in service & (Bus & tractor)	ISO 2631-1	Not reported *seat pan	Representative sample bus (n=11) and tractor (n=53) During actual driving condition	NA	Frequency weighted acceleration (a_{wx}, a_{wy}, a_{wz}) & a_v (vector sum) r.m.s	Postal Questionnaire -Annual amount of car driving, mileage (km/years) -Total driving experience (years)	Total vibration dose: $\sum a_{vi}t_i$ (years m^2s^{-4})	Vehicles Manufacturer & Model	-LBP associated with cumulative vibration dose -Total vibration dose > 4.5 years m^2s^{-4} significantly high OR for all types of back symptoms
Futatsuka et al/ 1998/ Japan	Cross sectional	Only one driver participated with 15 years of experience & (Agricultural machinery)	ISO 2631-1 (1985)	B&K type 4322 seat pad accelerometer *seat interface	Sample (n=10) common agricultural machine in Japan During actual work condition, test route chosen with four different runs	NA	Frequency weighted acceleration (x,y & z), vector sum	NA	NA	Speed	-WBV on the seats of combine harvesters and wheel tractors exceeded exposure limits and fatigue-decreased proficiency boundary limit of 8 hours
Nishiyama K et al/ 1998/ Japan	Cohort	Follow up from the participant in previous study (n=89) -Inclusion: triplets matched with age & years of tractor driving & (Tractor)	ISO 2361-1 (1978)	Piezoelectric accelerometer *seat surface	Sample (n=8) types of tractor selected by union During actual working involving four conditions, 40km distance	Until completion of tasks	Frequency weighted acceleration (x,y & z)	Questionnaire (self-administered) -years of tractor driving	NA	Tractor model	-The air suspension model seemed to induce less LBP than steel suspension models
Schwarze et al/ 1998/ Germany	Longitudinal	Association insured >30 company obliged to provide subjects (willingness & availability), n=388 follow up n=310 [n=281(RR=90.6%)] -Inclusion: regular exposure >10 years, 30-40years old & (Forklift Truck, Truck, Earth Moving Machine)	NA	NA	NA	NA	Data from vibration machinery (VIBEX database) -Frequency weighted energy equivalent acceleration for each homogenous period of exposure in (a_{zw})	Interview -Hours/day, days/week, weeks/year	Cumulative Vibration Dose $D_{v}=\sum a_{zw,i(8h)}.d_i$	Rough ground, vehicles: suspension/ tyre/seat, inspection or statement	-Vibration exposure considered as health hazard to the lumbar spine & probability of lumbar syndromes caused by vibration exposure rises with ↑vibration dose -Limit value for individual lifelong vibration dose should base on daily reference $a_{zw(8h)}$=0.6m/s^2

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Palmer K.T et al/ 2000/ UK	Cross sectional	Random community sample (n=22194, RR 58%) working age men & women & Source of exposure identified: (Car, van, forklift truck, lorry, tractor, bus, loader, dumper, excavator, off road car, helicopter, armoured vehicle)	BS 6841	NA	NA	NA	Frequency weighted acceleration (a_{wz}) assigned based on category vehicles from reference list	Postal Questionnaire -current exposure to WBV based on current occupation & industry -driving or riding from the listed vehicles	Estimated dose of vibration	NA	-7.2 million men & 1.8 million women in GB exposed to WBV at work in a one-week period -e VDV of > 374000 men & 9000 women exceed the proposed BS action level of $15ms^{-1/.75}$ (come from forklift truck, mechanical truck, farm worker, road good vehicles)
Dundurs J/ 2001/ Latvia	Cross sectional	One drivers participated & (Trolley bus)	ISO 2631-1	B&K type 4322 triaxial seat pad accelerometer *driver/seat interface	Sample trolley car (n=5) different model At four different runs selected	3 hours for each car in four runs	Frequency weighted acceleration (x, y & z) r.m.s, vector sum	Interview -daily vibration exposure time	Estimated daily vibration dose	Car models, Different loading	-Seat vibration differ older & young model of car (estimated daily vibration exposure for older model $>8.5ms^{-1.75}$)
Johanning E et al/ 2002/ Germany	Cross sectional	Service operation in mainline track in the Northeast corridor, Midwest & California (n=8) -Inclusion: 10-30 years in service & (Locomotives)	ISO 2631-1 (1997)	Three seat accelerometers (Endevco, Type 7265A-HS) *seat & floor & wall	Follow the normal scheduled person (n=22) vibration measurement conducted During normal operation time	155min range 84min to 383min	(a_w) r.m.s in x,y & z, (a_v), MTVV, VDV	NA	NA	Track condition/ class, speed & locomotive characteristics	-Locomotive rides characterized by relatively high shock content (acceleration peaks) of the vibration signal in all directions
Palmer K.T. et al/ 2003/ UK	Cross sectional	Community sample of n=22194, RR (58%) (men & women) at working age & Source of exposure identified: (Car, van, forklift truck, lorry, tractor, bus, loader, dumper, excavator, off road car, helicopter, armoured vehicle)	BS 6841	NA	NA	NA	Frequency weighted acceleration (a_{wz}) assigned based on category vehicles from reference list	Postal Questionnaire -current exposure to WBV based on current occupation & industry -driving or riding from the listed vehicles	Estimated dose of vibration	NA	Modest excesses of LBP and sciatica with exposure to WBV & no consistent relation with dose

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Funakoshi M et al/ 2004/ Japan	Cross sectional	Driver from Nissan Motor Co., Ltd., (n=12) & (Taxi)	ISO 2631-1 (1997)	RION PV-62 triaxial seat pad accelerometer *driver seat	Nissan crew taxis (n=12) During actual working condition, driven around Fukuoka City	4 hours	Frequency weighted r.m.s acceleration (x, y & z), vector sum	Interview & company record -Total driving time -Total mileage	NA	Road surface, car mileage	-Frequency weighted r.m.s accelerations of the taxi fell into potential health risks zone -Shortening of working hours & taking of rest break
Hoy et al/ 2005/ UK	Cross sectional	Company request to investigate risks for LBP (n=23) & (Forklift Truck)	ISO 2631-1	Liberty mutual WBV meter 2.0 *seat pan	All drivers involved in 12 actual working condition	5 minutes	Weighted r.m.s, peak, CF and VDV r.m.q	Questionnaire (interview) -Amount of driving (duration	NA	Road surface (grainy tarmac/ asphalt & concrete)	-Drivers exposed with acceptable levels of x & y axis (< 0.5m/s^2 as recommended by EU Physical Agents Directive) but not z axis
Rehn B et al/ 2005/ Sweden	Cross sectional	Volunteer participation of worker from previous study contacted via phone & (Terrain Vehicles (ATVs): snow groomers, snowmobiles forwarders)	ISO 2631-1 (1997)	Bruel & Kjaer 4322 *driver seat	Sample of ATVs (n=19) During actual operation	NA	Frequency weighted acceleration (x,y &z), vector sum, CF,MTVV, VDV	NA	NA	ATVs model & year of manufacturing	-Vibration magnitude in ATVs considerably high than the EU's action value & HGCZ in ISO 2631-1 -Dominant vibration direction varies depending on machine type
Bovenzi et al/ 2006/ Italy	Longitudinal	Part of VIBRISKS 4years project at 4 regions, Male drivers, random selection (n=598), RR:92-97% -Inclusion: minimum 1year driving experience & (earth moving machine, articulate truck, forklift truck, stake truck, freight container, garbage truck/compactor, track type loader, bus)	ISO 2631-1	NA *seat interface	Representative samples of machine/vehicle (n=74) During actual operating condition	NA	Frequency weighted r.m.s (a_{wx},a_{wy},a_{wz}) a_v (vector sum) & dominant value	Questionnaire (interview) -total employment year, daily & cumulative driving duration	-Daily [A(8)]: $a_w(T/T_0)^{1/2}$ -Cumulative: $\sum a_i^m t_i$	NA	-LB at 12mth/ intensity/disability significantly ↑ with↑ cumulative vibration dose -regular trend of associated with vibration dose $\sum a_{vi} t_i$ (ms^{-2}h) equal with acceleration & lifetime duration. -Not significant with daily dose
Okunribido et al/ 2006/ UK	Cross sectional	Distribution of Questionnaire in 8 predefine occupational group from different organization/ affiliation (n=394, RR:60.6%) -Inclusion: 1years completed at present job or had at least 5years driving experience & (police driver, tractor, truck/van, pilot, bus, construction, taxi)	ISO 2631-1 (1997)	Liberty mutual WBV meter 2.0 *seat pan	Sample of vehicles (n=24) During actual work tasks	5 minutes	Frequency weighted in (a_x,a_y & a_z), vector sum (r.m.s)	Self-assessment Questionnaire (postage) -year of driving & daily driving hour	-Total vibration dose (TVD): $\sum a_i^2 t_i$ (years m^2 s^{-4})	Vehicle condition (seat design)	-Produced excess of LBP risk for TVD not significant -Significant linear dose response for posture & MMH -Vibration in shock/jerking more important than regular sinusoidal events

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Okunribido et al/ 2006/UK	Cross sectional	Convenient sampling of the Short haul delivery driver (n=64, RR 58%) -Inclusion: min 5 years in present job or 5 years deliver driving & (van, articulated truck, tipper truck)	ISO 2631-1 (1997)	Liberty Mutual WBV meter 2.0 *driver seat	Sample from 3 vehicles (n=12 driver) During actual work condition	5 minutes	Frequency Weighted (x,y & z) r.m.s (m/s^2), peak acceleration, CF and VDV ($m/s^{1.75}$)	Self-assessment Questionnaire (postage) -year of driving -daily driving hour	NA	Surface & environment	-Delivery vehicles generate acceptable levels of average r.m.s acceleration -Travel on cobble associated with high CF (>9) & VDV (>15$m/s^{1.75}$)
Okunribido et al. 2007/UK	Cross sectional	Convenient sample take part as volunteer, urban bus driver (n=80, RR 85%) -Inclusion: 1 year present job or 5 years driving experience & (mini bus, single & double decker bus)	ISO 2631-1 (1997)	Liberty Mutual WBV meter 2.0 *driver seat	Sample of 3 bus models (n=12 driver) At simulated service route	5 minutes	Frequency Weighted (x,y & z) r.m.s (m/s^2), peak acceleration, CF and VDV ($m/s^{1.75}$), Fatigue Decreasing Frequency (FDP)	Self-assessment Questionnaire -year of driving -daily driving hour	NA	-Surface of road (idling, moving asphalt, cobble) -Vehicles years of manufacturing	-Vector sum values level exceeded limit European Directive -Single & double decker bus CF>9 and VDV> 15$m/s^{1.75}$ during travelling on cobble particularly in y, x axes
Tamrin et al/ 2007/ Malaysia	Cross sectional	11 bus company in central, north & eastern regions in Malaysia (6 states), n=760 -Inclusion: stage buses or local buses (short distance operation take & release passenger) & (Bus)	ISO 2631-1	Meastor Human Vib Meter (01DB-Metravib, Lyon) *drivers seat	Sample (n=132)	25 minutes	Frequency Weighted r.m.s acceleration (x, y & z)	Self-administered Questionnaire (under guidance of RA) -year of employment -duration of driving per day/per week -length to complete single trip -total bus trip per day -duration of rest	($a_{r.m.s\ action}$)= $0.5[8/t_h]^{1/2}$ ($a_{r.m.s\ limit}$)= $1.15[8/t_h]^{1/2}$	Road surface	-r.m.s value for all axes did not exceed both action level & exposure limit value -r.m.s showed that there were low risk if developing LBP from exposure to WBV
Eger et al/ 2008/ Canada	Cross sectional	Test location & models of HDL determined by Technical Advisory Committee (convenient sample, n=7) & (Load-Haul-Dump (HD) mining vehicles)	ISO 2631-1 (1997) & ISO 2631-5	10g tri-axial accelerometer by NexGen Ergonomics *seat interface	Sample from n=7 At 4 typical work duty cycle	Completed duty cycle ranged 1-2hr	-Frequency weighted (a_{wx}, a_{wy} & a_{wz}), vector sum, peak acceleration, CF & VDV, highest frequency weighted r.m.s -unweighted z axis r.m.s	Estimated operating hour of operated as determined via consolation from Technical Advisory Committee (7 hours per day)	-Daily dose: A(8) & VDV -S_{ed} & *R Factor*	Different model of HDL	3/7 LHD monitored above HGCZ in ISO 2631-1 but lower than predicted risks in ISO 2631-5

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Tiemessen et al/ 2008/ Netherlands	Longitudinal	Part of VIBRISKS study 13 comp willing to participate; T0, n=315, RR 55.2% T1, n=263, RR 56.7% -Inclusion: Male, 1hr per week exposure to WBV & (Lawn moving, wheeled loader, excavator, lorries, dumpers, steamroller, tractors, bulldozer, mobile crane, boats, asphalt machine)	ISO 2631-1 & VIBRISKS protocol	Tri-axial seat accelerometer type 1700 (Bruel & Kjaer) *driver seat	Representative sample of vehicles (n=49) In actual field	30 minutes	-Frequency weighted (a_x, a_y & a_z) r.m.s & r.m.q, vector sums & maximum axis	Self-administered Questionnaire -total hours operating vehicles	Daily; A(8) & VDV using max/vector sum Cumulative: $\sum a_i^m t_i$	NA	-Dose response pattern between WBV and driving related LBP -Exposure duration is the main instigator of revealed dose response
Rozali et al/ 2009/ Malaysia	Cross sectional	Military Armoured Vehicles driver, n=159, RR:90.8% selection based on universal sampling -Inclusion: drove armoured vehicles > 3 month & present in camp during data collection & (Tracked & Wheeled Army Vehicles)	ISO 2631-1 (1997)	Human Vibration Meter (MAESTRO, 0.4-1000Hz) *drivers seat	Sample (n=102) At selected tar-road-surface design	30 minutes	Frequency weighted r.m.s acceleration (x, y & z), vector sum	Self-administered Questionnaire	Estimated vibration dose value	Road surface. speed	-The mean estimated VDV at z axis in tracked armoured vehicles exceeded EAV > 9.1$ms^{-1.75}$ but did not exceed ELV < 21.0$ms^{-1.75}$ -WBV exposure at x axis were significant risk factor for LBP
Bovenzi/ 2009/ Italy	Prospective cohort	Part of VIBRISKS employed in several industries (n=537) -Inclusion: Male, 1 year driving experience & (Earth moving machine, articulated dumper, off road car, forklift truck, freight container, mobile crane, garbage truck/compactor, bus)	ISO 2631-1 & VIBRISKS protocol	Three uniaxial ICP accelerometer PCB type 356B40 *seat interface	Representative machine/ vehicle (n=68) took 700 vibration samples during actual operation, typical work cycle	10 minutes	Frequency weighted r.m.s & r.m.q acceleration (a_{wx}, a_{wy}, & a_{wz}) Vector sum & maximum axis	Questionnaire (Interview) employee & employer & company record -estimated daily/weekly exposure -driving hour -full time driving year	Daily; daily driving time, A(8) & VDV using max/vector sum Cumulative: $\sum a_i^m t_i$	Road surfaces	-↑ risk for high pain intensity & disability over time (lesser extend 12mth) with ↑ cumulative vibration dose (r.m.q) -measure of exposure duration in daily/lifetime provide good indication of LBP
Bovenzi/ 2010/ Italy	Prospective cohort	Part of VIBRISKS employed in several industries (n=202 not affected with LBP @ initial study) -Inclusion: Male, 1year driving experience & (Earth moving machine, articulated dumper, off road car, forklift truck, freight container, mobile crane, garbage truck/compactor, bus)	ISO 2631-1 & VIBRISKS protocol	Three uniaxial ICP accelerometer PCB type 356B40 *seat interface	Representative machine/ vehicle (n=68) during actual operation, typical work cycle	10 minutes	Frequency weighted acceleration (a_{wx}, a_{wy}, & a_{wz}) in r.m.s & r.m.q	Questionnaire (Interview) employee & employer & company record -estimated daily/weekly exposure -drvg hr -full time driving yr	Daily; daily driving time, A(8) & VDV using max/vector sum	Road surfaces	Duration of daily exposure exposures to WBV provide good prediction of LBP. Alternative measure of $VDV_{sum/max}$ gave better prediction than $A(8)_{sum/max}$

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Type of vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Raffler N et al/ 2010/ Germany	Cross sectional	Occupational male drivers (n=10) -Inclusion: 5 years' experience, no medical health complaint & (tram, helicopter, saloon car, van, forklift, mobile excavator (2), wheel loader, tractor, elevating platform truck)	ISO 2631-1	NA *seat surface & seat mounting point	Sample (n=10) During actual operation	Based on job tasks (37 min to 1hr 54 min)	Frequency weighted acceleration (x,y & z), Vector sum	NA	Value of a_v combined w posture score	NA	-Combination of WBV & posture exposures, the tractor driver & elevating platform truck driver exhibited the highest workload
Lewis & Johnson/ 2012/ USA	Cross sectional	Seattle Metro bus (n=13) & (Bus)	ISO 2631-1 & ISO 2631-5	Seat pad ICP accelerometer (model 356B40; PCB Piezotronics) *seat & floor interface	(n=13) At standardize test route (52km): city street/speed hump/ freeway	Completed test route	Frequency weighted (x, y & z) r.m.s, r.m.q, CF	Interview -daily exposure	A(8), VDV, Acceleration dose value (D_k), static spinal compression dose (S_{ed})	Road surfaces	-Road type had significant effect on all the vibration parameters z-A_w(8) exceeded limit value on freeway, z-VDV(8)&S_{ed} above limit in city street & speed hump -Bus WBV exposures were twice as high relative to car -Bus seat amplified rather than attenuated the WBV
Anne Harris et al/ 2012/ Canada	Case control	Resident of British Columbia, Canada (total n=808; n=405 with Parkinson & n=405 control) & (Ferry, crane, car, train, semi-trailer truck/light truck, subway, caterpillar, excavator, van, boat, grader, plane, forklift, bulldozer, helicopter, tractor, motorcycle/dirt bike, loader, dump truck, tank, marine craft, snowmobile, harvesters)	NA	NA	n= 292 (36%) exposed to WBV at work	NA	Metrics of exposure intensity of equipment extracted from literature Max (a_i)	Questionnaire (interview) -past hx of duration of exposure (estimated mean hr per week)	Dose 2[nd] Power: $\sum a_i^2 t_i$ (m^2s^{-4}) Dose 4[th] Power: $\sum a_i^4 t_i$ (m^4s^{-8})	NA	The 2[nd] power dose metric correlated with total duration of exposure but the 4[th] power dose metric somewhat less (increased emphasis on exposure intensity)
Thamsuwan et al/ 2013/ USA	Cross sectional	Driver worked in municipal city (n=12, high floor bus) & (n= 15, low floor bus) & (Bus)	ISO 2631-1 (1997) & ISO 2631-5 (2004)	ICP accelerometer (model 356B40; PCB Piezotronics) *seat & floor surface	All driver At standardized test route includes 4 roads types & no passenger during non-peak hour	75 min	Freq weighted (x,y & z axis) r.m.s & r.m.q, CF	Not reported clearly	A(8) VDV(8) D_k (8) S_{ed} (8)	Bus design & model, road surface	-WBV exposures were significantly higher in the high floor coach bus on the road segment w speed humps -Seat attenuate 10% of the floor transmitted vibration & amplified the vibration exposure on speed humps

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & (Typeof vehicles)	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Mayton et al/ 2014/ USA	Cross sectional	Worker in a quarry, (n=5, 3HTs & 2FELs) & (haul truck (HTs) & front-end wheel loader (FELs))	ISO 2631-1 (1997) & ANSI S3.18 guidelines	Triaxial accelerometer (model 356B18, 356B40) *seat & floor surface	Sample (n=10) vehicles During actual work operation	22.1 minutes to 98.9 minutes	Frequency weighted (x,y & z axis) r.m.s & r.m.q	Data from management estimated exposures of 9 to 10 hour/shift	Daily dose	Load/non-load, speed, load capacity, vehicle age, seat	-↑ HT speed ↑ recorded vibration at the chassis & seat -HT dominant axis (y axis) predominantly within HGCZ -Several instances VDV above ELV
Paschold et al/ 2015/ USA	Cross sectional	Monitoring for the most common used for automated collection (n=3) Inclusion: 1 year experience & (solid waste collection trucks)	ISO 2631-1	Quest Technology HAVPro Human Vibration Meter *seat driver interface	Sample (n=3) types of vehicles During normal operation hour on 2 consecutive day, run under similar route	8 hours	Frequency weighted (x,y & z axis), vector sum, CF	Estimated daily exposure of 8hr	Daily dose	NA	-The average WBV exposure value (0.99ms^{-2}) above action value of 0.5ms^{-2} but below limits value of 1.15ms^{-2} -The exposures level suggests the presence of potential health risks
Johnson et al/ 2015/ USA	Cross sectional	Full shift operators (n=8, 190 ton, n=14, 240 ton & n=18, 320 ton) & (heavy equipment vehicle (HEV)	ISO 2631-1 (1997) & ISO 2631-5 (2004)	Triaxial seat pad (model 356B40; PCB Piezotronics) *seat and floor surface	Each HEV operator During actual working condition	12 hours	Frequency weighted (x,y & z axis) r.m.s & r.m.q, vector sum	Estimated exposure per shift (12 hours)	Daily dose A(8) VDV(8) S_{ed} (8)	Different model of HEV, speed	-Predominant axis A(8) & VDV exposures were below ISO/EU, however all vector sum exposures were above action limit
Kim J.H. et al/ 2015/ USA	Randomized control trial	Part of series of baseline measurement of study (n=98) from diff comp w support from association & (Long Haul Truck)	ISO 2631-1	Triaxial seat pad accelerometer (Model 356B40; PCB Piezotronics) *seat & floor interface	All driver *regular work schedule (8-12 hours)	continuous for work schedule	Frequency weighted (x,y & z) & vector sum (r.m.s & r.m.q)	Interview Daily exposure	A(8), VDV	Road surface, speed	-Results demonstrated substantial diffrent in health risks prediction between predominant axis vs vector sum (vector sums above action limit) -VDV values on seat were 29% to 32% higher than floor measurement (seat amplified value)

Table 2.5: continued

Author/ Year/ Country	Study Design	Study population & *Type of vehicles	Measurement				Exposure Assessment			Factors influenced WBV	Key reported outcomes
			Standard	Equipment *site	Sample groups	Duration	Acceleration Magnitude	History of exposure	Calculation of dose		
Marin L.S et al/ 2016/ USA	Cross sectional	Sample of HEV operator (n=60) -Inclusion: average 14 year of experience & (heavy equipment vehicle (HEV): bulldozer, front loader, grader, scraper, water truck, 190-ton truck)	ISO 2631-1	ICP accelerometer (model 356B41; PCB Piezotronics) *Not reported	Sample of HEV (n=20) During continuous monitoring during actual operation involved 2-3 shift	Ranged (54 hours to 99 hours)	Frequency weighted (x,y & z) & vector sum (r.m.s & r.m.q)	Estimated exposure per shift (8 hours)	A(8), VDV	NA	-Predominant axis WBV exposures were above the ISO daily vibration action limit & the vector sum WBV exposure were considerably higher. -HEV operators exposed to high levels of both continuous & impulsive WBV exposures
Ab Aziz et al/ 2016/ Malaysia	Cross sectional	Malaysian Army (MA) driver (n=not reported) & (three tonne truck)	ISO 2631-1 (1997)	Bruel & Kjaer Type 4524 triaxial piezoelectric accelerometer *driver seat	Sample (n=4) truck tested on selected route (tarmac vs dirt) & different speed	reading repeated 3 times for each route	Frequency weighted r.m.s acceleration, vector sum, CF, VDV	Not reported clearly	VDV	Speed, road surface, duration of vehicles in service	-Rough road exhibit higher VDV variation as the vehicles speed change -VDV(8) increased gradually with increasing vehicle speed

RR, Response Rate; CF, Crest Factor; NA, Not Available; OR, Odds Ratio; VDV, Vibration Dose Value
*Site of measurement
↑ Increased
>Above

2.1.4 Dose Response Relationship

As defined by most medical dictionary, dose response is simply defined as a relationship in which a change in the amount, intensity or duration of exposure is associated with a change in risk of specified outcome. In a linear dose response relationship, the response is proportional to the dose, thus if the dose is doubled the response is also doubled. In a linear no threshold relationship, any dose, regardless of size, can theoretically cause a response, however some responses occur at certain range of doses only.

WBV exposures is defined as the product of the exposure intensity (expressed in acceleration) and exposure time to calculate for exposure dose (Tiemessen et al., 2008). Prediction of health hazard caused by WBV generally assumed the dose response pattern. Subsequently, increased duration of exposure (within the working day or daily over years) and increased vibration intensity mean increased vibration dose and ultimately lead to increased risk of LBP (ISO, 1997).

Indisputably the equivalent vibration magnitude and duration of exposure are two main components determining the hazard to health caused by WBV (Schwarze et al., 1998). However, it is suggestive that exposure duration is the main instigator of the revealed dose response relationship in driving related LBP than vibration magnitude (Lis, Black, & Nordin, 2007; Tiemessen et al., 2008). Moreover, the pattern of the odds ratios from logistic analysis indicated that vibration magnitude was related to low back symptoms to lesser extent than duration of exposure to WBV (Bovenzi, 1996). Another study reported that back pain increases with duration of exposure, but it does not increase with the estimated mean vibration magnitude. Moreover when duration of exposure is used instead of vibration dose to form exposure categories the trend of increasing prevalence with increasing vibration exposure become weaker for all types of back pain with exception of treated back pain (Boshuizen et al., 1990). Thus, reporting on whole body vibration dosages is required because reporting on single entity separately might underestimate the important for each parameter. Indeed, vibration dose measure performs slightly better as a measure of exposure than the number of driving years (Boshuizen et al., 1990). Increasing vibration dose indicates a higher probability of lumbar syndrome attributed to vibration and total vibration dose are proven to be a valuable predictor for degenerative process of the lumbar spine (Schwarze et al., 1998). Both parameters have the abilities of influencing the outcome.

Time is one of the important factor that influence the impact of driving to the development of low back pain among drivers. The time spent on driving may exaggerate the risks developing health hazards among the drivers. Studies conducted in the past revealed that the number of working hours was the only variable associated with occurrence of LBP. In these studies drivers with LBP had on average an hour longer working hour (Andrusaitis, Oliveira, & Barros Filho, 2006). In terms of total duration of exposure, it was found that driving ≤ 5 years, 6-15 years and > 16 years had 1.1%, 2.14% and 7.1% respectively increase in estimated prevalence of lumbar spondylolisthesis (Chen, Chan, Katz, Chang, & Christiani, 2004). In this study, this authors also reported that the OR for low back pain among taxi drivers was 3.4 for exposure of > 15 years compared to only 2.6 for drivers with ≤ 5 years exposure. These finding are consistent with findings from other studies involving professional drivers and in agreement with previously established dose response relationship between duration of exposure to WBV and LBP among professional drivers.

Even though dose response relationships were accepted to be important in assessment of WBV exposures, epidemiological evidence to support this is limited. This limitation is partly contributed by the adaptation of the cross sectional study design in most of the studies (Bovenzi, 1996; Bovenzi & Hulshof, 1999a; Hulshof & Zanten, 1987; Lings & LeboeufYde, 2000; Magnusson et al., 1998).

2.1.5 Occupational Safety Demands

In view of the links between exposure to WBV and ill health, a safety standard has been created that suggests the level above which exposure is deemed to be particularly hazardous for operators (Salmoni et al., 2008). Hence, directive and regulation has been formulated to ensure health and safety in workplace complete with recommended control measure to minimize the risks from WBV. These recommendations are based on assessments of the risk and exposure.

The International Standard, ISO 2631-1 is a widely accepted standard for WBV assessment and provide guidelines on how to properly measure and interpret WBV exposure in relation to human health and comfort (Killen & Eger, 2016). The ISO standard is constantly being reviewed that the previous version of the ISO 2631-1:1985 updated to the version of ISO 2631-1:1997. The new addition of ISO 2631-5:2004 gives guidelines for the evaluation of vibration containing multiple shocks. Much of the setup following the ISO 2631-1 except that the acceleration values are used to calculate a daily equivalent static compression dose (Sed), and a risk factor (R factor) value (Killen & Eger, 2016) however the limitation of the ISO 2631-5 is that it has not been validated at the population level.

The International Standard usually become the cross reference for the formulation of other standard document that produce within certain region or country, for instances the Australian Standard, AS 2670-2001 adopted the complete International Standard for evaluation of human exposure to WBV (Foster & van Leeuwen, 2007). Meanwhile other document available such as the British Standard, BS 6840:1987 differ from the International Standard as it does not specify vibration exposure limits but indicates that a daily vibration dose of 15 $ms^{-1.75}$ may be expected to be associated with severe discomfort and increased risk of injury (Lines et al., 1994) whereas for the European Directive 2002 it allows the use the predominant axis as opposed to the International Standard that also suggests to use the vector sum exposures when more than one predominant WBV exposures axes exist.

In Malaysia, the Department of Occupational Safety and Health Ministry of Human Resources Malaysia, produced the Guideline on Occupational Vibration (Department of Occupational Safety and Health Ministry of Human Resources Malaysia, 2003). The guideline is intended to increase awareness among employers as well as employees on the effect of vibration to human body and provide guidance on how to avoid or prevent the risk of vibration related discomfort and damage to the human body. The recommendation and formulation of the Threshold Limit Values (TLV) outlined in this guideline were adapted from ISO 2631-1, 1985 standard. However, the guidelines only limited to the acceleration component in root-mean-square (r.m.s) as a measure of acceleration magnitude.

2.1.5.1 Health Guidance Caution Zone

The International Standard ISO 2631-1:1997 provide exposure guidance based on the Health Guidance Caution Zone (HGCZ) which provide limits for frequency weighted r.m.s acceleration levels (or equivalent vibration dose values) based on exposure duration (Salmoni et al., 2008). Apart from using the highest magnitude for health risk assessment the International Standard also suggests the use of vector sum exposures when more than one predominant WBV exposures axes exist (Gryllias, Yiakopoulos, Karamolegkou, & Antoniadis, 2016).

The HGCH is the area between a set of parallel lines consists of lower and upper boundary values which define the probability of health risks based on the magnitude of vibration exposure between four to eight hours (Killen & Eger, 2016). The upper and lower boundaries of the eight-hour HGCZ for frequency-weighted r.m.s accelerations, A(8), are 0.9 m/s^2 and 0.45 m/s^2 respectively and 17 $m/s^{1.75}$ and 8.5 $m/s^{1.75}$ for the eight-hour equivalent VDV (Gryllias et al., 2016; Killen & Eger, 2016). However, ISO 2631-

1:1997 standard did not clearly define specific health effects in some of the caution zones. For exposure level below the caution zone, the guidelines says, "health effects have not been clearly documented and/or objectively observed". For exposure within the caution zone, the guidelines says, "caution with respect to potential health risks is indicated", and for exposure level above the caution zone, "health risks are likely". The guidelines did not provide a clear guidance for action (Salmoni et al., 2008) as stated in the European Directive which define the action and limit values.

The HGCZ illustrated as a graphical representation in Annex B of the ISO 2631-1:1997 for evaluation of exposure risk as illustrated in Figure 2.1. There are two such sets in the graph, being the first one uses the duration of exposure and acceleration magnitude in r.m.s values (a_w) in x and y coordinates respectively to determine the severity of exposure. Evaluation of a point P (x,y) plotted according to the duration (x axis) and magnitude (y axis) of an exposure.

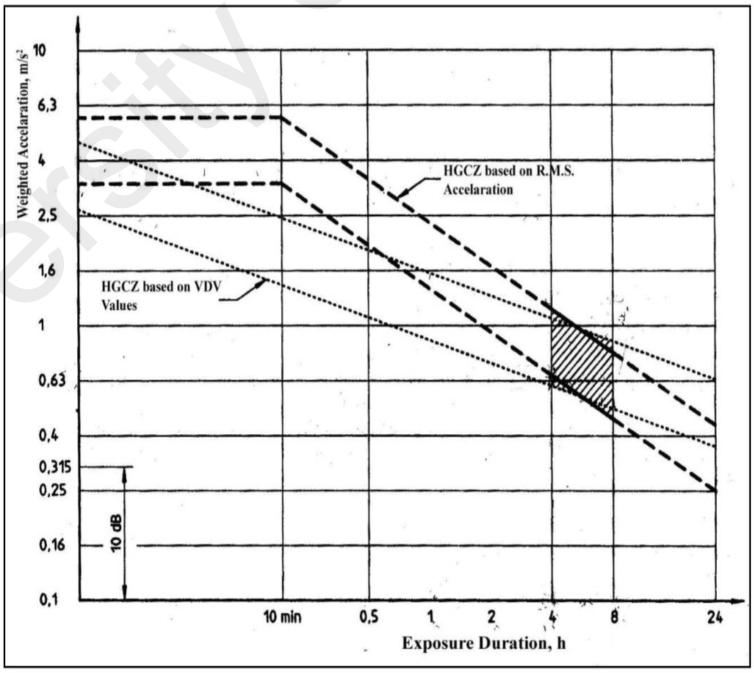


Figure 2.1: Health Guidance Caution Zone (HGCZ) Described in ISO 2631-1:1997

2.1.5.2 Exposure Action Value and Exposure Limit Value

The European Directive builds on existing general employer's duties to manage risks to health and safety, introduces exposure action and limit values for both hand-arm vibration and WBV, and setting minimum standards for the control of vibration risks across Europe (Nelson & Brereton, 2005). Thus, the settlement of the exposure action value (EAV) and exposure limit values (ELV) provide clear guidance for action (Salmoni et al., 2008). The directive has been implemented in most European countries since July 2005 (Donati et al., 2005) and allows for the use of predominant axis WBV exposures (Gryllias et al., 2016).

EAV is the amount of daily exposure to WBV above which employers are required to act to reduce risk and control the exposure. The daily EAV is expressed as an 8-hour energy-equivalent frequency-weighted acceleration known as the A(8). Alternative to this measure is the vibration dose value (VDV) (Nelson & Brereton, 2005). The EAV reported in A(8) with value of 0.5 m/s^2 is corresponds to VDV with values of 9.1 $m/s^{1.75}$ (European Parliment and the council of European Union, 2002). WBV risks are low for exposures around the action value and only simple control measures are usually necessary in these circumstances (HSE, 2005b). However if the exposure action value was exceeded, they are certain requirements that employers must comply as required under the Directive 2002/44/EC (European Parliment and the council of European Union, 2002). The employer shall establish and implement a program of technical and organizational measures that intended to reduce to a minimum exposure to mechanical vibration. The following recommendations are to be considered : (i) Other working methods that require less exposure to mechanical vibration, (ii) Appropriate work equipment of ergonomic design, producing the least possible vibration, (iii) Provision of auxiliary equipment that reduces the risk of injuries, such as protective gloves or special seats, (iv) Appropriate maintenance programs for work equipment , (v)

Design and layout of workplaces, (vi) Adequate information and training to instruct workers to use work equipment correctly and safely, (vii) Limitation of the duration and intensity of the exposure, (viii)Work schedules with adequate rest periods, (viiii) Provision of clothing to protect workers from cold and damp.

On the other hand, the ELV is the maximum amount of vibration an employee may be exposed to on any single day. The ELV values can be reported in A(8) with the recommended value of 1.15 m/s^2 and in VDV with recommended value of 21 $m/s^{1.75}$. In any event, workers shall not be exposed to vibrations above the exposure limit value as recommended by the Directive 2002/44/EC (European Parliment and the council of European Union, 2002). If this should be the case, the employer shall take immediate action to reduce exposure below the ELV. The methods used may include sampling, which must be representative of the personal exposure of a worker to the mechanical vibration in question.

The vibration directive also provides added value by establishing agreed levels of exposure above which employers must take certain action to control risks, and in setting the daily exposure limits (Nelson & Brereton, 2005). The directive lays down minimum requirements for the protection of workers from the risks arising from vibrations. The general requirement by the directives include responsibilities of the employers such as (i) assessing risk and exposure, (ii) planning and implementing the necessary control measures, (iii) providing and maintaining suitable work equipment, (iv) providing workers with information and training on risks and their control and (v) monitoring and reviewing the effectiveness of the risks control programme (Nelson & Brereton, 2005). Compliance to this regulation and directive is needed for the protection of workers exposed to vibration. Reduction in the exposure for occupational risks will reduce the outcome and severity of health hazards.

2.1.6 Adverse health impact to human

All persons living in developed or developing countries might experience at least one source of exposure to WBV. Exposure to WBV among civilian mostly comes from usage of own or public transportation (i.e. car, bus, train, helicopter). However, their risk is probably less intense in comparison to occupational exposure. Population based survey done among residents of United Kingdom found that 56% of employed man and 19% of employed women reported to at least one source of occupational WBV exposure (Palmer et al., 2000). In this study, the sources of mechanical vibration in the workplace were from hand tools, machinery and vehicles. Among the economic sectors involved were construction (63%), mining and manufacturing (44%), agriculture (38%), electricity, gas and water supply (34%) transport and communication (23%) (Donati et al., 2008).

Indeed, this is a widespread physical hazard that commonly found at the workplace with approximately affected men three and a half time more than women (Donati et al., 2008).

The effects of vibration may be manifold. The human responses to WBV exposures lead to effects on psychomotor, physiological or psychological (Burgess & Foster, 2012), which may present as a temporary or chronic phenomenon (Nakashima, 2004). At best they may only cause discomfort and interference of activities but at worst they may cause injury or disease (Mcphee, Foster, & Long, 2009). Short term or low amplitude vibration can be described as a source of annoyance to human as it can interfere with speech communication, affect concentration and cause sleep disturbance (Nakashima, 2004). However, they may also induce symptoms of abdominal pain, headache, chest pain, nausea, vertigo and shortness of breath (Burgess & Foster, 2012; Government of Alberta, 2010). Nausea and vertigo are believed to be effects of WBV to the inner ear that control balance whereas the chest pain, headache and abdominal pain are possibly a response to increased blood pressure (Government of Alberta, 2010). Other known effects of vibration are decreased performance level as a result of vibration effects to cognitive, hearing, motor control and vision (Nakashima, 2004). However symptoms of acute exposure to vibrations generally end within minutes or hours from interruption of the exposures (Government of Alberta, 2010).

Apart from the acute symptoms, vibration also believed to cause a range of problems such as disorder of joints and muscle especially the spine, cardiovascular, respiratory, endocrine, metabolic changes, digestive system and female reproductive (Mcphee et al., 2009). Exposure to WBV in combination with prolonged sitting posture may contributes to the occurrence of varicose veins and hemorrhoids (Griffin et al., 2008). Exposure to vibration also believed to cause disruption of vascular functions (Harris et al., 2012).

Even though WBV had many known adverse health effect, epidemiological evidence to support WBV-induced disorder of other organ systems other than lower back is limited (Bovenzi, 1996). LBP is known as one of the long term pathological effect of WBV (Nakashima, 2004). WBV induced LBP is believed to be preceded by herniated disc and early degeneration of the spine (Griffin et al., 2008; Mcphee et al., 2009; Nakashima, 2004). The exact mechanism how WBV affects the spine is still unclear and require a multidisciplinary research approach to prove.

2.1.7 Review on epidemiological studies of WBV exposures towards human spinal structures

2.1.7.1 Method

The musculoskeletal disorder induced by WBV exposures are more likely due to inflammation and injury to the spine. However, the exact mechanisms of what happen at intervertebral level that lead to low back disorder were still unclear. Extensive search for suitable epidemiological studies that evaluate the true impact of WBV towards spine morphology were conducted in the database of PubMed, Science Direct, Springer Open and Google Scholar. A combination of keywords and phrases used in the search were professional drivers, health impact of WBV, spine, lumbar, and LBP. The original articles related the intended topic were retained for further use. Each study was analysed and summarised in tabular form under listed headings: (i) author, year of publication and country of origin; (ii) study design; (iii) methods to assess the WBV exposures; (iv) WBV parameters; (v) subjects and (vi) key reported outcomes (see Table 2.6).

2.1.7.2 Results

Fifteen original articles were included in the review (Ayari, Thomas, Doré, & Serrus, 2009; Ayari, Thomas, Doré, Taiar, & Dron, 2009; Bazrgari, Shirazi-Adl, & Kasra, 2008; Cronin, Oliver, & Mcnair, 2004; El-Khatib & Guillon, 2001; Fritz & Schäfer, 2011; Hampel & Chang, 1999; Huber, Skrzypiec, Klein, Püschel, & Morlock, 2010; Li et al., 2015; Maikala, Bhambhani, & King, 2006; Pankoke, Hofmann, & Wolfel, 2001; Seidel, Blüthner, & Hinz, 2001; Seidel, Hinz, Hofmann, & Menzel, 2008; Wang, Bazrgari, Shirazi-adl, Rakheja, & Boileau, 2010; Yoshimura, Nakai, & Tamaoki, 2005). A presentation of the study characteristics presented in Table 2.6. The data extracted from the description of evidence were the authors, year of publication, country of origin, study design, methods, WBV parameter, subjects involved and the key reported outcomes.

All extracted articles were clearly described as experimental studies. A big part of the assessment were directly at biodynamic mechanism occurred at spinal structure especially the lumbar region, however three articles performed indirect assessment, such as assessing changes in the body height preceded by exposures to WBV (Hampel & Chang, 1999), assessing muscle stiffness (Cronin et al., 2004) and measuring cardiac output (Maikala et al., 2006). Even though the assessments were not directly observed at spinal level, the studies were able to elicit adverse effects with direct implication on the spinal structure. One of the adverse effects observed in this review were changes in vertebral disc height that lead to pressure changes (Hampel & Chang, 1999), impaired performance of musculoskeletal structure (Cronin et al., 2004) and demonstration of higher metabolic rate (Maikala et al., 2006).

All studies clearly described the methods they used to conduct their experiment. Most of the researchers assessed WBV exposures in a seated posture except for one which assessed WBV in standing position (Cronin et al., 2004). The main report on impact of WBV to the spinal structure were on the prediction of the spinal loads, muscles activities and trunk stability. Some articles described their health risks based on cumulative fatigue failure (Ayari, Thomas, Doré, Taiar, et al., 2009; Seidel et al., 2008) or assessments via stress analysis and injury risks factor (Ayari, Thomas, Doré, & Serrus, 2009). One study used in vitro specimens of a functional unit to look at fatigue strength information and estimate the spinal loading through observation of end plate and bone mineral density (BMD) examined via CT scan (Huber et al., 2010). Some of the researchers created a specific condition like influence of different posture such as comparing the erect, leaning backward with or without back support (El-Khatib & Guillon, 2001), erect and flex (Bazrgari et al., 2008), neutral and flex (Huber et al., 2010).

Most of the researchers clearly defined the characteristics of WBV exposures prescribed for their experiments except for two articles (Ayari, Thomas, Doré, Taiar, et al., 2009; Pankoke et al., 2001). Three of the studies generated the specific WBV pattern to simulate real field exposures such as semi-truck tractor driven on the secondary road (Hampel & Chang, 1999), container bridge crane during normal work process (Fritz & Schäfer, 2011) and exposures following five types of vehicles namely forklift, wheel loader, truck, excavator, forwarder and harvester (Seidel et al., 2008). The rest of the studies generated their WBV exposures in laboratory setting using work seats with vibrating base (Maikala et al., 2006) or shaker table (Bazrgari et al., 2008). The frequency of vibrations tested in this review ranged from 0 to 30Hz (Cronin et al., 2004). However, majority of the studies tested vibrations of 10Hz to 20Hz. The maximum acceleration magnitude prescribed for testing were 40m/s^2 (Ayari, Thomas, Doré, & Serrus, 2009).

Majority of the experimental study used finite model as test subjects except for four studies that involved healthy men (Cronin et al., 2004; Hampel & Chang, 1999; Li et al., 2015; Maikala et al., 2006). One study used un-embalmed cadavers (El-Khatib & Guillon, 2001) and another study took the in-vitro specimen of functional spine unit from young man aged 20 to 40 years old and old man aged 50 to 60 years old (Huber et al., 2010).

The experimental studies to determine the impact of WBV to human spine found that changes occurred at spinal level as indicated by existence of cyclic loading of the nucleus pulposus while a more complex phenomena occurred at the vertebral bodies (El-Khatib & Guillon, 2001). Exposure to WBV lead to active mechanism that change the intervertebral disc height which were directly associated with pressure changes (Hampel & Chang, 1999). Apart from that, flattening of the lumbar lordosis from erect to flexed posture and antagonistic coactivity in abdominal muscles noticeably increased force on the spine while substantially improved trunk stability (Bazrgari et al., 2008). It is also reported the relative displacement between vertebral bodies which input affects at L4 and L5 (Yoshimura et al., 2005) with areas exposed to the highest fracture risk are the cancellous bone of the vertebral body and vertebral endplate (Ayari, Thomas, Doré, & Serrus, 2009). Other than that WBV exposures also had significant role of muscle in trunk biodynamic and the associated risk to back injuries (Bazrgari et al., 2008). Muscle activities were higher under vibration than without vibration (Li et al., 2015). Physical work load during WBV may lead to greater metabolic response (Maikala et al., 2006).

The extent of the intraspinal forces depends on several factors such as multiple excitation of different body parts, stature and posture (Seidel et al., 2008). A bent forward posture essentially augments the compressive and shear stress forces (Fritz & Schäfer, 2011; Seidel et al., 2001). Injury risk increases with the age due to loss of mechanical properties i.e. young modulus, bone density, ultimate stress and damping of vertebrae (Ayari, Thomas, Doré, & Serrus, 2009; Ayari, Thomas, Doré, Taiar, et al., 2009). Another study proven that the element of low BMD on older subject failed the fatigue failure strength even though adapting the neutral posture and superimposed in young subject when adapted the flexed posture combined with low BMD (Huber et al., 2010).

Vibration effects on the intervertebral discs have frequency dependencies with relative angle displacement between L4 and L5 showed largest relative transmissibility at frequency of 12Hz (Yoshimura et al., 2005). Estimated peak spinal loads were substantially larger under 4Hz excitation frequency as compared to 20Hz with contribution muscle force exceeding that of inertial forces (Bazrgari et al., 2008).

2.1.7.3 Discussions

It is apparent from the epidemiological review that spinal system has a characteristic response to vibrational inputs. The effects could be varying and involved dynamic mechanisms but interests to study more concern at the lumbar region proved that musculoskeletal disorders induced by WBV mainly manifested as LBP. The most common occupational exposures to WBV also noticed more among drivers hence experimental studies mostly observed the impact in a seated posture.

The two-impact reported on the reviews were the internal forces acting in the vertebral bodies and the muscular activities. The forces created within the spine due to exposures to WBV have been considered as an important cause of degenerative changes whereas the repeated compression in the region of the vertebral end plate caused fatigue failure serve as primary damage which initiate the WBV related disease to the spine (Seidel, Bluthner, Hinz, & M. Schust, 1998), such as herniated disc. The higher muscular activities upon exposure to WBV indicate muscles fatigue that may not be able to endure further loading hence influence the likelihood of injury induced by vibration.

In the reviews, certain confounder such as personal characteristics (age, anthropometric) and posture were observed, and impact were reported. There can be large variations between subjects with respect to biological effects thus, different person has different susceptibility in the development of back disorders. Impact of the posture adapted does influenced the rate of transmissibility as certain posture induced the effect of WBV. Other review paper reported the similar finding (Pope & Hansson, 1991; Wilder & Pope, 1996). The WBV identified as complex oscillatory motions which impact influence by the magnitude and frequency, the greatest magnitude of vibration transmitted to the spine at frequencies of (4.5 to 5.5) Hz and (9.4 to 13.4) Hz (Nakashima, 2004).

On top of that cautions must be exercised as majority of articles evaluate in this review studied the impact of WBV in experimental set up using the finite model. The observed changes might not be a true effect in a living subjects. However, in vivo studies are scarce and very difficult to obtain (Huber et al., 2010). Although cadaveric specimens are consider as best fitted physiological and anatomical model to test WBV on, they too have major limitations due to the absence of myoelectric activity, body temperature and their conservative state (El-Khatib & Guillon, 2001). However, simple biodynamic model coupled with in vivo and in vitro data permitted a preliminary deduction of quantitative relationships between WBV and spinal health with the considerations of individual factors and exposure conditions (Seidel, 2005). Indeed, exact mechanism that involved yet need to be explored to understand more of the dynamic effect towards exposure to WBV. However, the association between risks exposures and the occurrence of symptoms are undeniable even though, WBV unlikely on its own to cause back pain. It was believed its work in combination with other occupational risk factor to superimpose or aggravate the symptoms of LBP.

2.1.7.4 Conclusions

In conclusions, the exposures toward WBV affected mainly the spinal structure that eventually manifested as LBP. There are confounding factors that might influences the manifestation of the health risks especially personal characteristics i.e. age, anthropometric measures.

Table 2.6: Summary of the Field Studies; Effect of WBV Exposures Towards Human Spinal Structure

Author/ Year/ Country	Study design	Methods	WBV parameter	Subjects	Key reported outcomes
Hampel & Chang/ 1997/ USA	Experimental study	-Exposure for 3 hr @ seated position -Measurement of body height hourly	-Generated in semi-truck tractor driven on 2nd road -z-axis, 1.6-10Hz, 0.885m/s^2	Male (n=12) Female (n=5)	-Subject growth by 1.14mm when exposed to vibration, & the (2 & 3) hr subject follow the natural tendency to shrink, end of 3hr, the body height was 2.23mm higher -Evidence of active mechanism for changing intervertebral disc height & the associated pressure change
El-Khatib & Guillon/ 2001/ France	Experimental study	-Exposure for 5 min @ 4 seated posture (erect/leaning backward; with & without lumbar support) -Measurement of intradiscal pressure @ L1/L2, L2/L3, L3/L4 & L4/L5 w pressure transducer inserted into disc	-Whole body, vertical, broad-band white random -0.8-25Hz, 1.5m/s^2 r.m.s	Unembalmed cadavers (n=7)	-The shape of the power spectral density function suggested the existence of a cyclic loading of the nucleous pulposus, while more complex phenomena were observed at the vertebral body -Energy of the intranuclear pressure variation decreased when leaning the backrest backwards -Effect of lumbar support depended on the discal level and on posture -The response of the lumbar spine cannot be assessed by examining only vertebral acceleration at one level
Pankoke et al/ 2001/ Germany	Experimental study	-Exposure to simplified model @ seated man (adaptable to body height, body mass and posture) -Prediction of spinal loads	-NA	Finite-element model	-Integral loading measures, such as spinal load may be predicted with simplified finite-element model -Individual exposure effect relationship may be predicted by this model due to the adaptability to specific subject -This method may provide data about bone acceleration that can be used in the process of model verification
Seidel et al/ 2001/ Germany	Experimental study	-Exposure to model for 10s, varies anthropometric & posture @ seat acceleration -Prediction of static & dynamic compression & shear forces acting on lumbar discs	-Random acceleration different combination of r.m.s levels & peak values -unweighted: 1.19,1.78,1.90, 2.45 ms^{-2} -frequency weighted 1.42,1.54,1.33 &1.84 ms^{-2} -peak: 7,10,10 &7 ms^{-2}	Finite element model	-A bent forward posture augments essentially the compressive and shear stress, predicted for erect and relaxed sitting posture -Normal variation of body mass & height causes a considerable variation of static internal shear stress but a minor variation of compressive pressure -Dynamic internal stress varies nearly proportionally to the body mass -Transfer functions from seat acceleration to compressive force depend significantly on the posture
Cronin et al/ 2004/ New Zealand	Experimental study	-Subject exposed to WBV using teeterboard @ standing with flat footed; 60s (X5) with 60s rest in between -stiffness of the triceps surae muscle group using force platform	-Vertical sinusoidal using Galileo™ 2000 a mechanical teeterboard -0-30 Hz & 1-6mm amplitude	Male (n=7) Female (n=4)	-Vibratory stimulation loading parameters used to enhance performance do not significantly alter muscle stiffness in untrained individuals
Yoshimura et al/ 2005/ Japan	Experimental study	-Exposure to model for 60s @ seated human body -measure the transmissibility using skin surface accelerometer	-Vertical excitation -Frequency up to 20Hz, amplitude of 0.07G r.m.s	Multi-body dynamic model	-Relative displacement of between vertebrae as a basis for assessment of vibration risks -Inputs affect the intervertebral disk between L4 & L5 among the five -Vibration effects on the intervertebral disks have frequencies dependencies, relative angle displacement between L4-L5 showed largest relative transmissibility at frequency of 12Hz

Table 2.6: continued

Author/ Year/ Country	Study design	Methods	WBV parameter	Subjects	Key reported outcomes
Maikala et al/ 2006/ Canada	Experimental study	-Exposure at work seat vibrating base @ 6min baseline, 8minWBV w or w/o back support, 4min recover, 8min WBV w opposite backrest & R hand max handgrip contraction 1min -measure cardiac output (carbon dioxide rebreathing)	-Vertical acceleration r.m.s; -6.1mm @ 3Hz (8.94ms^{-2}) -6.4mm @ 4.5Hz (8.99ms^{-2}) -6.6mm @ 6Hz (9.11ms^{-2}) -Mean acceleration at 3, 4.5 & 6 Hz – 0.9$g_{r.m.s}$	Healthy male (n=13)	-Absolute and relative oxygen uptake demonstrated significantly greater responses during sitting without backrest than with backrest -Heart rate and oxygen pulse responses were significantly greater during WBV combined with hand grip contractions than during WBV alone -Physical work during WBV will enhance greater metabolic response -Despite low metabolic rates during WBV the effect of aerobic fitness suggest importance of physical activity in occupational exposed WBV
Seidel et al/ 2008/ Germany	Experimental study	-Exposure to FE adaptable to different posture & anthropometric parameters @ seat, backrest, feet and hands on mobile machinery -predict intraspinal compressive & shear force based on assessment of health risks (cumulative fatigue failure)	-Exposure condition generated in 5 group: Forklift, Wheel loader, Truck -Excavator, Forwarder, Harvester	50 finite element (FE) model	-The extent of intraspinal forces under WBV depends on several factors like multiple excitations of different body parts, stature and posture, the effects of these forces are determined by individual tolerance -Cumulative fatigue failure is an important mechanism responsible for WBV-related injury
Bazrgari et al/ 2008/ Canada	Experimental study	-Exposure in shaker table @seat; different posture (erect & flex) ± analysis abdominal coaxtivity -predict trunk biodynamics (muscle force, spinal load & trunk stability)	-Vertical acceleration -Frequency 4-20Hz, gravity acceleration of 9.8m/s^2 (0.5-4g)	Finite element model	-Estimated peak spinal loads were substantially larger under 4Hz excitation frequency as compared to 20Hz with the contribution of muscle forces exceeding that of inertial forces -Flattening of the lumbar lordosis from erect to a flexed posture & antagonistic coactivity in abdominal muscles both noticeably ↑ forces on the spine while substantially improving trunk stability -Significant role of muscle in trunk biodynamic & associated risk to back injuries -High magnitude accelerations in seat vibration especially at near resonant frequency expose the vertebral column to large forces and high risk of injury by significantly ↑ muscle activities in response to equilibrium & stability demands
Ayari et al/ 2009/ Canada (a)	Experimental study	-Exposure to model composed of 33 bodies of lumbar rachis w different no of motion segment @seat -stress in the lumbar rachis (stress analysis & injury risk factor)	-High level of acceleration: imitate shock during rough road (10, 20 & 40 m/s^2)	Parametric finite element model	-Stress analysis: areas exposed to the highest fracture risk are the cancellous bone of the vertebral body and vertebral endplate -Injury risk factor increases with the age and consequently that the excitation amplitude must be limited to lower levels when age increases

Table 2.6: continued

Author/ Year/ Country	Study design	Methods	WBV parameter	Subjects	Key reported outcomes
Ayari et al/ 2009/ Canada (b)	Experimental study	-Exposure of model (lumbar rachis) @seat -dynamic stress & mechanical fatigue failure predicted in L4-L5 (model of fatigue failure to estimate the risk of adverse health effect due to mechanical vibration)	-Random excitation	Parametric finite element model	-Injury risk increases with the age due to loss of mechanical properties (young modulus, bone density, ultimate stress & damping of the vertebral disc) -Excitation acceleration applied to the seat must be limited to levels lower than 2.3m/s^2 (endurance limit of fatigue behaviour) to avoid any risks independently of the driver's age and morphology
Huber et al/ 2010/ Germany	Experimental study	Exposure to in vitro specimen with different posture (young neutral, young flexed, old neutral) -estimate spinal loading (fatigue strength information: end plate &BMD via CT scan)	-300000 cycles of sinusoidal compression (-18h) peak to peak load 0 k N to 2 k N with frequency of 5Hz	In vitro specimen of functional spinal unit (young man:20-40yo, old man: 50-60yo)	-The product between endplate area & BMD was shown to useful to predict fatigue strength for older donor & should therefore be considered with regard to WBV injuries -No failure of the young specimen in neutral posture but 4 specimens from older donor with low BMD failed -In flexed posture 2 specimen from young donor failed (attributed to low BMD & another one unexplained leaving the influence of flexion yet unclear)
Wang et al/ 2010/ Canada	Experimental study	Exposure to model with prescribed kinematics data @ seated (represent automotive seats with WBV simulator) -prediction of muscle force & spinal loads	-White noise vibration spectrum in the 0.5 to 15Hz frequency range with broadband excitation r.m.s acceleration values of 0.25, 0.5 & 1 m/s^2	Finite element model of spine	-Crucial role of muscle forces in the dynamic response of the trunk -Muscle force, while maintaining trunk equilibrium, substantially ↑ the compression and shear forces of the spine, hence the risk of tissues injury
Fritz et al/ 2011/ Germany	Experimental study	Exposure at model consists of 29 rigid bodies connected by ideal joints @ seated position -force transmitted in lumbar spine (compressive force and shear forces dorsoventral (L3, L4) & (L5, S1))	-Vibration generated from container bridge crane during normal work process	Biomechanical model	-The ↑ of the spine force is the result of the ↑ muscle forces stabilizing the inclined trunk -The typical posture of the container bridge crane or fork lift trucks (forward inclination) enhanced spinal forces compare to upright sitting posture (risks analysis of workplace)
Li et al/ 2015/ China	Experimental study	Rigid body model @ seated in adjustable car seat exposed in randomized order on 3 separate days -muscle activity modelling (displacement o seat-pan & head to obtain seat to head transmissibility, muscle oxygenation using spectroscopy)	-Vertical vibration at (3, 4.5, 6. 7 & 8) Hz	healthy subjects (n=10)	-Muscle activity of the lumbar suddenly ↑ at backrest inclination angle of 5° & vibration frequency of 5 Hz -Muscle activity was higher under vibration than without vibration -Vibration frequency significantly affected the muscle activity of the lumbar area

↑, increase; BMD, Bone mineral density; NA, Not Available; Hz, Hertz

2.2 Professional Drivers

2.2.1 Definition

Oxford dictionary defines a professional as a person engaged in a specified activity as one's main paid occupation rather than as an amateur. The person must be competent, skillful and assured to perform that activity. Therefore, a professional driver, can be defined as a person who is competent, skillful and assured to operate motor vehicle or machinery professionally

A driver’s job description by the Public Services Commission of Malaysia, is a person who is responsible for implementing the purview drive vehicle that requires a driver's license from the Department of Road Transport and maintain vehicle or machinery under his supervision that are always clean and safe for each trip. Among the vehicles or machinery covered by this service schemes are cars, vans, four-wheel drive light vehicles, buses, trucks, dumpers, rollers and agricultural tractors.

The competent driving license (CDL) issued by Department of Road Transport in Malaysia is divided into several classes applicable to operate different types of vehicles. The CDL license can be suspended or revoked subjected to the 15-point by Road Traffic Offenses System or also known as KEJARA (Kesalahan Jalan Raya) and must be renewed with option available for yearly (http://www.jpj.gov.my/sistem-kejara), within two, three or five years. For the vocational driving license (VDL) or commercial driving license, it is produce especially for commercial vehicles involving buses and trucks. VDL is jointly issued by the Road Transport Department and the Commercial Vehicle Licensing Board. There are several classes of licenses available i.e. class D (cars with unloaded weight not exceeding 3500kg), E (Trucks-all classes), E1 (Trucks with unloaded weight not exceeding 7500kg), E2 (Trucks with unloaded weight not exceeding 5000kg), F (Tractors/Light motorized machines (wheeled) with unloaded weight not exceeding

5000kg), G (Tractors/Light motorized machines (chained) with unloaded weight not exceeding 5000kg), H (Tractors/Heavy motorized machines (wheeled) with unloaded weight exceeding 5000kg) and I (Tractors/Heavy motorized machines (chained) with unloaded weight exceeding 5000kg).

2.2.2 Overview of Transportation Industry in Malaysia

Data from the Department of Statistic Malaysia (DOSM) shows that 4.4% of employed people by industries in Malaysia for the year of 2014 were involved in the transportation and storage industry. The top three industries in Malaysia were dominated by the wholesale and retail trade and repair of the motor vehicles and motorcycles industry at 16.8%, followed by manufacturing industry at 16.7% and the agricultural, forestry and fishery industry at 12.3% (Jabatan Perangkaan Malaysia, 2015). The percentage of laborer in Malaysia year of 2014 showed that our market for working population dominated by males by 61.4% comparative to only 38.4% among female's population (Jabatan Perangkaan Malaysia, 2015).

In line with development of certain countries the need for improvement in transportations and logistics system must be parallel. Logistic services not only confined to transportation but other services i.e. warehousing, storage and inventory management services, freight forwarding/customs clearance and shipping services, Integrated Logistics Services (ILS), International Integrated Logistics Services (IILS) and Cold Chain Facilities (Malaysian Investment Development Authority, 2012). A great future expansion is expected involving in this industry. Furthermore, the Malaysian Economic Planning Unit (EPU) developed a Logistics and Trade Facilitation Masterplan to provide the strategic direction for the development of the logistics industry to further improve its productivity and competitiveness (Economic Planning Unit, 2015).

Data from Malaysia's Road Transport Department showed a steady increased in number of accumulated registered vehicles. In the year 2016, the estimated total number of registered motor vehicles were 956 430, of which a 552 427 were cars and station wagon and goods and other vehicles of 163 277 (Land Transport Authority Malaysia, 2016). The number of registered taxis and buses were 27 534 and 18 804 respectively (Land Transport Authority Malaysia, 2016). It is clearly shown in this data that more and more of our drivers are exposed to driving activities especially vehicles classify under small and medium size category. Despite these huge numbers, there is no documented monitoring conducted especially for these types of vehicles. Generally, we assumed that these type of use vehicles produce low vibration magnitude, however this is just mere assumption as there is no published data so far.

In Malaysia, the basic qualification needed to become a driver was lower secondary school certification with basic salary ranged from RM 1, 218.00 to RM 2,939.00. The initial basic salary is determined based on types of license owned by the drivers i.e. License D starting basic salary of RM 1,264.15, License E/E1/E2 start at RM 1,310.30, License F/H start at RM 1,356.45 and License G/I start at RM 1,402.60 (Public Services Commission of Malaysia, http://www.spa.gov.my).

2.2.3 The Health of Professional Drivers

The lifestyles of the bus driver at home and at work is inextricably linked to his or her physical and psychological health. However, the predisposition to ill health as a result of their job was only clear concluded based on studies conducted the last 50 years. (Tse, Flin, & Mearns, 2006). A review of studies conducted earlier consistently reported that bus drivers have higher rates of mortality, morbidity and absenteeism due to illness compared to employees from wide range of other occupational groups (Winkleby, Ragland, Fisher, & Syme, 1988).

There are certain risks factors experienced by professional driver's specific for their work environment that can predispose them to certain disorders. The main stressor identified involved in their work environment were physical environment i.e. cabin ergonomics, violence, traffic congestion, job design i.e. time pressure, shift patterns, rest breaks, social isolation and organizational issues i.e. reduce driver decision-making authority (Tse et al., 2006). Another study reported a multilevel worksite-induced strains i.e. long work hours and fatigue, shift work and sleep deprivation, postural fatigue and exposure to noise and vibration, sedentary lifestyles and unhealthy diet, exposure to diesel exhaust fumes and other occupational stressors (Apostolopoulos, Sönmez, Shattell, & Belzer, 2010).

Apart from a risk which is specific to their work environment, other factor such as individual characteristic and lifestyles does play major roles to superimpose the ill health condition among drivers. Smoking is more common among professional drivers than in other working population with overall prevalence of smoking among bus drivers was 93% in Dhaka (Goon & Bipasha, 2012). A high prevalence of obesity was found in a study among commercial truck drivers whereby 93.3% of the respondents had a body mass index (BMI) of 25 or higher (Turner & Reed, 2011). There is sufficient global evidence that professional drivers are less active than is the general population (Apostolopoulos et al., 2010; Taylor & Dorn, 2006). Furthermore, drivers who had at least one health condition engaged in significantly less aerobic exercise, used fewer strengthening exercises, did not exercise for 30 minutes continuously and had a higher BMI (Turner & Reed, 2011). The development of MetS (metabolic syndrome) is a notable health problem among Iranian long distance drivers that could be related to sitting in fixed position for long hours while working, cigarette smoking, job stress, unhealthy diet and lack of physical activity (Mohebbi et al., 2012).

Due to this multi involvement risks hence it certainly induced the occurrence of certain medical condition among professional drivers. As reported, the health issues among bus drivers resulting from specific stressor comprises of certain physical health i.e. cardiovascular disease, gastrointestinal problems, musculoskeletal disorders, fatigue and other physical health outcomes, psychological health i.e. depression, anxiety, post-traumatic stress disorders, behavioral outcomes i.e. alcohol use, tobacco use, drug use with element of organizational outcomes i.e. absenteeism, labor turnover, accidents (Tse et al., 2006). Another critical review further categorized these health conditions into six primary morbidities for truckers classified as (i) psychological and psychiatric disorders, (ii) detriments resulting from disrupted biological cycles, (iii) musculoskeletal disorders, (iv) cancer and respiratory morbidities, (v) cardiovascular disease and (vi) risk-laden substance use and sexual practices (Apostolopoulos et al., 2010).

Occupation as a driver exposed them to many other health conditions, however the most common ailment reported were musculoskeletal disorders which is mainly LBP. Despite large number of epidemiological studies conducted in the past two decades the etiology and risk factor of work related back disorders are not well understood (Burdorf & Sorock, 1997). On top of that low back pain is multifactorial in origin with superimposed risk factors making it harder to identify the sole risk factor.

2.3 Low Back Pain

2.3.1 Definition

Low back pain (LBP) is a symptom rather than a disease or a diagnosis. It is a symptom that cannot be validated by an external standard and a disorder with many possible etiologies that can occur to any groups of population with many definition (Manchikanti, 2000).

The symptoms of LBP can be defined and classified according to the anatomical site, its causes and clinical courses. Based on anatomical site, low back pain is defined as a pain which is localized between the 12th rib and the inferior gluteal folds, with or without leg pain (Krismer & van Tulder, 2007).

Based on it causes, low back pain is commonly differentiated between non-specific low back pain and specific low back pain. The term of non-specific low back pain is used when the pathoanatomical cause of the pain cannot be determined (Maher, Underwood, & Buchbinder, 2016) or with no known underlying pathology (Krismer & van Tulder, 2007). Specific low back pain is restricted to low back pain with known etiology namely degenerative conditions, inflammatory conditions, infective and neoplastic causes, metabolic bone disease, referred pain, psychogenic pain, trauma and congenital disorders (Krismer & van Tulder, 2007). Some also defined causes of back pain by using the mechanical disorder of low back pain and manifestation of systemic illness including non-mechanical spinal condition and visceral disease (Diamond & Borenstein, 2006). Mechanical disorder may results from problems with the various spinal structures including ligaments, facet joints, periosteum, the paravertebral musculature and fascia, blood vessels, the annulus fibrosis and spinal nerve roots, however the exact disorder causing the symptoms often remains unidentified (Diamond & Borenstein, 2006). Hence the mechanical causative of low back pain interchangeable to the term of non-specific low back pain, as no confirmation of the definitive causative.

Description of low back pain based on its clinical courses can be divided into acute, subacute and chronic low back pain. Acute low back pain occurs suddenly after period of a minimum of 6 months without low back pain and lasts for less than 6 weeks. Subacute low back pain occurs suddenly after a period of 6 months without low back pain and lasts for between 6 weeks and 3 months. Chronic LBP has duration of more than three months (Costa et al., 2009), or occurs episodically within 6-month period (Krismer & van Tulder, 2007). Others define it as pain that lasts beyond the expected period of healing, and acknowledge that chronic pain may not have well-defined underlying pathological causes (Andersson, 1999). Others classify frequently recurring back pain as chronic pain since it intermittently affects an individual over a long period (Andersson, 1999).

To certain extent LBP also can be described in a bigger spectrum, ranking the pain intensity or severity and disability caused by LBP itself. It is often described as how the back pain affecting daily life due to the pain they experienced until it leads to difficulty in performing activities. They are example of questionnaire being developed to ascertain such as Quebec Back Pain Disability Scale, Roland-Morris Disability Questionnaire and Oswestry Low Back Pain Disability Questionnaire.

The definition of LBP was often unclear and the physiological mechanisms causing LBP were often not considered (Gallais & Griffin, 2006). Most of the studies used vague terminology to describe this condition; in fact, there is no consensual definition of LBP. Only the symptoms and anatomical site of the pain is similar but other dimension on describing the pain take a different measure. Variation in terms of the definition used to explain the spectrum of LBP can directly affected the outcome of measurements such as the prevalence among a particular study population.

Case definitions for LBP in existing epidemiological studies vary widely and this is addressed by standardizing case definitions across studies (Hoy et al., 2010). A standardized definition of LBP will assist future reviews, enable greater comparisons between countries, and ultimately lead to a far-improved understanding of LBP (Hoy et al., 2012). On top of that clarity in case definitions is critical in to improve knowledge not only on the underlying conditions but also the risk factors and consequences (Videman & Battié, 2012). Hence emphasis should be given to define the symptoms of LBP. Precise description of LBP allows for better comparison with other study done elsewhere in the future.

2.3.2 Epidemiology and Natural History of Low Back Pain

LBP has a major impact globally (Hoy et al., 2010) and is extremely common problem that most people experience at some point of their life (Hoy, Brooks, Blyth, & Buchbinder, 2010). LBP is a considerable public health problems that can affect people of any age and socioeconomic class (Majid & Truumees, 2008), however as the population ages, the global number of individuals with LBP is likely to increase substantially over the coming decades (Hoy et al., 2012).

In the United States, the prevalence of LBP is ranging from 8% to 56%. An estimated 28% of their population experience disabling LBP sometime during their lives with life time prevalence of 65% to 80% (Manchikanti, 2000). Prevalence of LBP is highest among female individuals aged 40 to 80 years (Hoy et al., 2012). The estimated mean annual prevalence was 38.1% (Hoy et al., 2010) and the mean monthly estimated prevalence was 23.2% (Hoy et al., 2012). Worldwide, 37% of LBP was attributed to occupation with twofold variation across regions., The attributable proportion was higher for men than women because of their higher participation in labor force and in occupation with heavy lifting or WBV(Punnett et al., 2005).The cause of high LBP prevalence in a population is often uncertain. According to the available medical history data from 26 million patients in Ohio, 1.2 million patients (4.54%) had a diagnosis of LBP (Shemory, Pfefferle, & Gradisar, 2016). Mechanical LBP (i.e. the source of the pain may be in the spinal joints, discs, vertebrae, or soft tissues) contributed to about 90% as causative for the occurrence of low back pain which commonly remain unidentified (Diamond & Borenstein, 2006). Another 10% of cases had specific causes identified under non-mechanical spinal condition and visceral diseases (Diamond & Borenstein, 2006). The contributing factors for specific causes commonly related to systemic medical condition such as multiple myeloma, spinal cord tumors, metastatic carcinoma, inflammatory arthritis, diseases of pelvic organ, renal disease, cholecystitis, penetrating ulcer and many more. Out of the specific causes of low back pain approximately about 1% could arise from serious spinal pathology and the assessment process needs to be sufficiently thorough to ensure that, they are correctly identified and managed accordingly.

People affected with LBP, especially with the acute form with associated disability usually improved rapidly within weeks (Pengel, Herbert, Maher, & Refshauge, 2003). However, once established as a chronic illness the prognosis is usually poor and many patient continue to have pain and disability for more than one year after the initial episode (Diamond & Borenstein, 2006). Chronic LBP has also become a diagnosis of convenience for many people who are actually disabled for socioeconomic, work related or psychological reasons (Andersson, 1999). The alarming threat of LBP is the great increase in the functional consequences, especially work disability (Krismer & van Tulder, 2007). Therefore, prevention is important due to its theoretically potential to reducing the problems.

There is a need to understand the risks associated with LBP to justify for the initiation and development of LBP and for restructuring existing preventive measures. Most reports conclude that LBP is multifactorial in origins. The risk factors for development of LBP can be divided into three most common identified group of factors i.e. individual factors (age, gender, height, weight, smoking, physical fitness, marital status and education), psychosocial factors (stress, anxiety, cognitive functioning, pain behavior) and occupational related factors (Burdorf & Sorock, 1997; Krismer & van Tulder, 2007). In the occupational risk factors, it can be further subdivided into physical factors at work (i.e. manual material handling, frequent bending and twisting, heavy physical load, static work posture, repetitive movement and WBV) and psychological factors at work (i.e. mental stress, job dissatisfaction, low job support, low job decision and monotonous work) (Burdorf & Sorock, 1997; Krismer & van Tulder, 2007). Addressing the modifiable risks especially those related to occupation seems to have better prospect as implementation of control measure can be imposed and monitored regularly.

It is undeniable that professional drivers are among the people at higher risks of developing LBP. Their work environment exposed them to the known risks associated with physical and psychosocial conditions at work.

2.3.3 Review on epidemiological studies for occurrence of work related musculoskeletal disorder (MSD) among professional drivers

2.3.3.1 Method

Most of the reviewed epidemiological studies were found from the database of PubMed, Science Direct, Springer Open and Google Scholar. The keywords used during electronic searches were LBP, WBV, professional drivers, MSD, risk factors. All epidemiological studies selected in the search were examined but only studies that fulfilled the following criteria were chosen for review: (i) The original articles must be an epidemiological study, (ii) The health impact investigated involve MSD and must investigate the development of LBP, (iii) confounding factors for development of LBP among professional drivers must be investigated. The original articles that fulfilled the above criteria were retained for further use. Each of the articles was analyzed and summarized in tabular form under the following headings: (i) author, year of publication and country of origin; (ii) study design and sample size; (iii) types of vehicles; (iv) assessment of MSD disorder especially LBP in term of methods of investigation and the definition used for LBP; (v) prevalence and incidence of LBP; (vi) confounder and (vii) key reported outcomes (see Table 2.8).

2.3.3.2 Results

Thirty six original articles were included in the review (Alperovitch-Najenson et al., 2010; Andrusaitis et al., 2006; Battié et al., 2002; Begum, Ahsan, & Nazmul A. Khan, 2012; Boshuizen et al., 1990; Bovenzi, 2009, 2010; Bovenzi et al., 2006a; Bovenzi & Betta, 1994; Bovenzi & Zadini, 1992; Chen, Chan, Katz, Chang, & Christiani, 2004; Chen et al., 2005; Fadhli, Humairah, Khairul, Kaswandi, & Zunaidah, 2016; Gyi & Porter, 1998; Hoy et al., 2005; Knox et al., 2014; Kumar et al., 1999; Luoma et al., 2000; Mansfield & Marshall, 2001; Miyamoto et al., 2008; Miyamoto, Shirai, Nakayama, Gembun, & Kaneda, 2000; Mozafari, Vahedian, Mohebi, & Najafi, 2014; Noda et al., 2015; Okunribido et al., 2006; Okunribido et al., 2006, 2007a, Palmer et al., 2003, 2008; Samuel & Babajide, 2012; Schwarze et al., 1998; Szeto & Lam, 2007; Tamrin et al., 2007; Tiemessen et al., 2008; Torén, Öberg, Lembke, Enlund, & Rask-Andersen, 2002; Virtanen et al., 2007). A presentation of the study characteristics of the 36 articles were reported in Table 2.8. Majority of the articles correctly described as cross-sectional studies design 25 out of 36 articles. Another 10 articles conducted using prospective cohort or longitudinal, one studies using retrospective database analysis (Knox et al., 2014) and one studies using case control (Palmer et al., 2008). The sampling population usually comes from predetermined group of drivers except for three articles; i.e. involved sampling at community level with consideration of adequate samples from industry involving exposure to WBV (Palmer et al., 2003), involved sample of those having LBP presenting for MRI in a catchment area with 252 number of cases which 185 comes from professional drivers (Palmer et al., 2008) and another article extracted information via database of Defense Medical Epidemiology for those with LBP as classified using International Classification of Disease (ICD) defined as military vehicles drivers (Knox et al., 2014). The professional drivers recruited in the review papers were dominated by male drivers except for one paper reported the involvement of female drivers (Szeto & Lam, 2007). The majority of types of vehicles come from class of heavy vehicles, taxis and buses however one article reported among train drivers (Virtanen et al., 2007) and another articles among three wheeler drivers (Noda et al., 2015).

a) Assessment of work related MSD especially the symptoms of LBP

The most common methods for the assessment of occupational related symptoms of MSD particularly among professional drivers were using the questionnaire. From this review, most of the researchers adapted the Nordic Musculoskeletal Questionnaire (NMQ) either directly or modified according to local use. However, 11 of the articles used their own validated questionnaires. Those assessed using questionnaire administered via face to face interview or self-reporting. Eight of the articles expanded their physical assessment using clinical evaluation methodology that include lumbar spine examination, hand grip strength, sit and reach test and observation of standing and sitting posture (Szeto & Lam, 2007). Some of the researchers in this review combined the clinical examination with diagnostic test i.e. standardize clinical examination of spine with lumbar X-ray (Schwarze et al., 1998), clinical evaluation by Orthopedic surgeon assisted by MRI (Kumar et al., 1999), confirmation of degenerative changes of the spine using MRI (Battié et al., 2002; Luoma et al., 2000; Palmer et al., 2008), review of medical records with standardized lumbosacral spine film (Chen et al., 2004) and lab investigation using genetic analysis to determine the phenotypes of intervertebral disc disease (Virtanen et al., 2007).

Most of the researches clearly defined their health outcomes. However, a wide variety of definitions were observed. The most commonly studied outcomes in this review were symptoms of LBP. Only one article specifically touched on the confirmative diagnosis of acquired spondylolisthesis (ASL) (Chen et al., 2004). Other measures to define the low back disorders includes lumbar syndrome, sciatica pain, disc protrusion, intervertebral disc disease, disc degeneration and lumbago. Furthermore, some researchers defined the symptoms of LBP assessing on the severity, intensity, disability, frequency, course of symptoms as in acute or chronic and treatment taken. For the assessment of pain intensity the researchers used a questionnaire which were adapted from Von Korff pain score (Bovenzi et al., 2006b) or Visual Analogue Scale (VAS) (Tiemessen et al., 2008) or Numerical Rating Scale (NSR) (Bovenzi, 2009). For the assessment of disability the Roland Morris Disability Questionnaire (RMDS) were commonly adapted (Bovenzi, 2009, 2010; Bovenzi et al., 2006b; Palmer et al., 2008; Tiemessen et al., 2008). Only assessment of LBP considering the anatomical location of lower back region and recall period for occurrence of the symptoms prior to data collection that seems standardized for majority reported in the articles. The recall period for the occurrence of symptoms mostly reported at lifetime, 12 months, four weeks, seven days prior and pain occurs in relation to tasks of driving. Two of the articles reported on the occurrence of previous symptoms at four years (Luoma et al., 2000) and three months (Virtanen et al., 2007).

b) Prevalence and Incidence of LBP among professional drivers

Majority of the articles reported on the prevalence or incidence of LBP based on the recall periods except for six articles; reported based on the frequency of diagnosis for lumbar syndrome which noted to increase with increasing dose of WBV exposure, for low exposures the frequency of diagnosis was 55.6%, medium exposure of 65.0% and high exposures of 73.2% (Schwarze et al., 1998), reported based on means (SD) of LBP occurred at 12 months prior (scale of one to seven) with means of 4.7 (2.3), LBP occurred at 12 months prior (scale of zero to one hundred) with means of 31 (31) and back pain interfering with daily activities in days with means of 18 (61) days (Battié et al., 2002), reported as estimated prevalence for diagnosis of ASL based on duration of working as drivers i.e. those exposed to driving within five years estimated prevalence of 1.1%, driving experienced for six to fifteen years with estimated prevalence of 2.4% and above fifteen years of 7.1% (Chen et al., 2004), reported based on median duration of the current episode of LBP of 1.0 (IQR: 0.5 – 2.2) (Palmer et al., 2008), reported based on incidence rate of LBP with 54.2 per 1000 person years (Knox et al., 2014) and one articles did not report on the prevalence and incident of LBP as the symptoms of LBP were mainly assessed to define the clustering of symptoms for latent class analysis (LCA) (Virtanen et al., 2007).

The articles reported on the prevalence of LBP ranged from the lowest as 3.6% among agricultural tractors drivers however depending on the description of LBP (Boshuizen et al., 1990) and the highest of 82.9% among bus drivers (Bovenzi & Zadini, 1992). It showed that prevalence of LBP occurred at lifetime ranged from 65.0% (Gyi & Porter, 1998) to 81.3% (Bovenzi & Betta, 1994). The occurrence of LBP at 12 months prior ranged from the highest reported as 82.9% among bus drivers (Bovenzi & Zadini, 1992) and the lowest of 30.6% among taxi drivers (Samuel & Babajide, 2012). The types of vehicles classified under machine drivers i.e. earth mover documented among those with high prevalence of LBP at 12 months of 74.4%, armoured vehicles of 73.6% more prominent among tracked army vehicles (Rozali et al., 2009) and 78.0% however for this articles the exact types of vehicles were not documented (Begum et al., 2012). It also showed that the shorter the recall periods the prevalence of symptoms reported lower comparatively as for LBP occurred at four weeks prior, it ranged from 15.5% to 50.3% and LBP at seven days prior ranged from 19.0% to 62.4%. Furthermore, the prevalence of LBP based on intensity and disability ranged from 8.5% to 24.6% and 5.7% to 19.2 % respectively. The prevalence of LBP related driving were 31.7% (Tiemessen et al., 2008). The summary of the finding as presented in Table 2.7.

Table 2.7: Summary of Prevalence of LBP Among Professional Drivers

No	Description on the LBP	Prevalence (%)
1	Occurrence of LBP in relation to quantification of WBV exposures:	
	Low	55.6 %
	Medium	65.0%
	High	73.2%
2	Occurrence of LBP in relation to duration of driving in years:	
	≤ 5	1.1%
	6-15	2.4%
	>5	7.1%
3	Occurrence of LBP according to time based:	
	Lifetime	65.0% to 81.3%
	12 months	30.6% to 82.9%
	4 weeks	15.5% to 50.3%
	7 days	19.0% to 62.4%
	Post driving	31.7%
4	Occurrence of LBP according to intensity and disability:	
	Intensity	8.5% to 24.6%
	Disability	5.7% to 19.2%
5	Occurrence of LBP according to types of vehicles:	
	Bus	82.9%
	Machinery (i.e. earth mover)	74.4%
	Tracked Army Vehicles	73.6%
	Taxi	30.6%
	Tractor	3.6%

c) Confounders

As discussed earlier the occurrence of LBP among professional drivers were influenced by combination of personal characteristics, psychosocial and work-related risk factors. The data for personal characteristics usually captured from questionnaires. However, for the psychosocial and work-related risks, the information was captured via utilization of specific tools or questionnaires. Undeniable that majority of the researcher attempted to evaluate on each of the known risk factors as it become the confounder between association of WBV exposures and development of LBP among professional drivers. Thus, to evaluate further on the occupational related risks specific assessment such as Ovako Working Analysis System (OWAS) (Hoy et al., 2005; Tamrin et al., 2007), Rapid Upper Limb Assessment (RULA) (Hoy et al., 2005), Participatory Ergonomics Intervention Approach (PEIA) (Samuel & Babajide, 2012) used for assessment of posture adapted at work place while Profile of Mood States (POMS) (Tamrin et al., 2007), Perceived Stress Score (PSS)(Noda et al., 2015), Job dissatisfaction subscale of the Job Content Questionnaire (JCQ) (Chen et al., 2005), and General Health Questionnaire (GHQ) (Rozali et al., 2009) were specifically implemented for assessment of psychosocial component. Some authors adapted methods to assessed on the posture and MMH via own systematic observation (Okunribido et al., 2006, 2007a).

d) Key reported outcomes

It is undeniable that risks for LBP and sciatica pain strongly affected by occupation (Luoma et al., 2000). In comparison helicopter pilot had highest prevalence of LBP of 80.6% in comparison to tractor drivers of 43.3% (Okunribido et al., 2006). It showed that the number of individual belonging to Intervertebral disc degeneration (IDD) phenotypes significantly higher among train drivers (Virtanen et al., 2007). IDD define as a variety of genetic variants involved and some are shared with variants predisposing to back pain.

The main reported outcomes showed that majority of the articles concluded on the involvement of occupational risk factors that worked in combination (not independently) to induced the high prevalence of LBP among professional drivers (Hoy et al., 2005; Rozali et al., 2009; Tamrin et al., 2007; Tiemessen et al., 2008) i.e. WBV with prolonged sitting and awkward or constrained posture (Boshuizen et al., 1990; Bovenzi & Zadini, 1992), daily lifting of weight more than 10kg at work (Palmer et al., 2003), driving with trunk considerably twisted or bent forward frequently (Chen et al., 2005; Hoy et al., 2005), combination of MMH and awkward posture (Bovenzi et al., 2006a; Okunribido et al., 2006). Involvement of personal characteristics i.e. age, BMI, smoking, marital status, back trauma, presence of disease other than LBP, suffering from fatigue, taller statue, frequent strenuous exercise, anthropometric mismatched were among those reported with significant association meanwhile for the psychosocial risks those identified i.e. low job decision and low job support. Furthermore some of the significant correlation such as shortage of spending time with family, irregular duty time, short resting time and long driving time in a day (Miyamoto et al., 2000) might induced stress related to occupation.

The significant of performing MRI as confirmatory diagnosis seems to have minimal impact as it showed that even though tractor driving farmers reported with backache more often than the non-tractor driving farmer but no significant different in terms of clinical assessment and MRI finding (Kumar et al., 1999) similar results also shown with disc degeneration between occupational drivers and their twin brother with no significant different being observed (Battié et al., 2002).

2.3.3.3 Discussions

From the review, it is proven that professional drivers are particularly at higher risk for developing MSD especially the symptoms of LBP. However due to the variation of the definition used for the symptoms of LBP extra caution needed when comparing one results to another on the incident and prevalence rates. One problem of low back disorder is great variability in the repeatability on physical examination and clinical conclusion (Pope et al., 2002). Hence to study the occurrence of LBP researcher need to adapt tools or questionnaire that able to determine.

It is suggested that we should look for populations at risk, rather than looking for risk factors (Leboeuf-Yde, 2004). Thus, epidemiological study in the past usually aimed among predetermined occupational group. The conceptual model developed for low back disorders among drivers identified potential contributing risk factors categorized into (i) intensity of WBV, (ii) duration of WBV, (iii) working posture of drivers, (iv) work environment and (v) psychosocial factors (Leelavathy, Raju, & Raj, 2013). All the risks worked in combination as observed that sitting by itself does not demonstrate an impressive risk association with LBP, however sitting in combination with WBV and/or awkward postures does increase the association with presence of LBP (Lis, Black, Korn,

& Nordin, 2007; Lis, Black, & Nordin, 2007). Regardless the fact that the impact of other (personal or work related) stressor may sometimes be more dominant than WBV, evidence of the relationship between WBV and LBP would justify by itself the attention of possibilities of prevention (Pope, Goh, & Magnusson, 2002).

2.3.3.4 Conclusions

In conclusions, professional drivers were among the specific group at risks of developing LBP due to their exposures toward WBV while driving. However, the risks factor might work in combination i.e. prolonged sitting, awkward posture, MMH and psychosocial stressor that could superimposed the occurrence of LBP.

Table 2.8: Summary of Study Characteristics; Epidemiological Studies of Work Related Musculoskeletal Disorder among Professional Drivers

Author/ Year/ Country	Study design	Types of vehicles	Assessment of MSD: Methods of investigation	Assessment of MSD: Definition	Prevalence/ Incidence of LBP	Confounder	Key reported outcomes
Boshuizen et al/ 1990/ Netherlands	? Retrospective (n=577)	Agricultural tractor	Q (postal) -7 items to assessed LBP	Back pain, back pain lasting several days or longer, back pain treated, back pain radiating to leg, frequent or long-lasting back pain, LBP, frequent or long-lasting LBP, prolapsed disc	Ranged from 3.6% to 45.8% depending on LBP description	Smoking, age, climatic condition, mental stress, physical load (lifting/posture/sitting/standing)	-Prevalence of reported LBP approximately 10% higher in tractor driver's vs worker non-exposed to vibration -Higher prevalence of LBP in tractor drivers might be (partly) caused by WBV but prolonged sitting & posture might also be of influence
Bovenzi & Zadini/ 1992/ Italy	? Retrospective (n=234)	Urban Bus	Q (postal) -? standardize NMQ	Recall period of LBP @lifetime/@12mth/ @7dy prior (+hx of disc protrusion/tx/duration/sick leave)	LBP@12mth 82.9% & @ 7dy 62.4% -Prevalence odds ratios (OR) exceeded 1 for bus drivers	Personal, posture (awkward), climatic working condition, stress	-Highest prevalence of disc protrusion among drivers with more severe WBV exposure -Frequent awkward posture at work relate to some types of low back symptoms -Bus driving a/w ↑ risk of low back troubles (excess risks due to both WBV & prolonged sitting in constrained posture)
Bovenzi & Betta/ 1994/ Italy	? Retrospective (n=1155)	Tractor	Q (interview) -modified version of NMQ	Recall period of LBP @lifetime, @12mth & @1mth prior (+ transient & chronic LBP, sciatica pain, disc protrusion, back trauma & accident)	LBP @lifetime (81.3%), @12mth (71.7%), @1mth (39.2%)	Personal, work environment, mental stress, previous job of heavy physical demand, hx of back trauma & accident, posture score & postural load	-Back accident & age significant predictor of LBP -Vibration exposure & postural load were independent contributors to ↑ risk for LBP according to multiplicative model
Schwarze et al/ 1998/ Germany	Longitudinal (n=388)	Forklift truck, truck, earth moving machine	-Standardize clinical examination of spine & lumbar X-ray -Data of health insurance on inability to work due to lumbar disorder	Lumbar syndrome (any symptoms in the lumbar region & in sacral area for which vertebral cause could be assumed *degenerative process of spine	Frequency of diagnosis rises from 55.6% (low exposure) to 65% (medium) to 73.2% (high)	Personal factors, past hx of spine injury, postural load due to leisure activities, occupational factor (carrying, lifting, twisted body posture)	The prevalence of lumbar syndrome was 1.55 times higher in highly exposed group when compared to the reference group
Gyi & Porter/ 1998/ UK	Cross sec (n=80)	Driving police officer	Q (interview) -standardized format of NMQ	MSD; lifetime, point prevalence of (7dy) & period prevalence (12mth, severity) -Area; neck, shoulder, elbow, wrist/hand, upper back, lower back, hip/thigh/buttock, knee, ankle, feet	-Lifetime prevalence of LBP 65% -Point prevalence (19%) -Period prevalence (45%)	Personal characteristics, work posture	-Most frequently reported body area low back (35%) -Exposure to car driving, both in term of distance & hr driven had significant effect on self-reported back trouble -Officer job mainly driving experienced more low back trouble over 12mth vs those job primarily sitting(non-driving), standing & lifting tasks

Table 2.8: continued

Author/ Year/ Country	**Study design**	**Types of vehicles**	**Assessment of MSD**		**Prevalence/ Incidence of LBP**	**Confounder**	**Key reported outcomes**
			Methods of investigation	Definition			
Kumar et al/ 1999/ India	Retrospective Cohort (n=50)	Agricultural tractor	-Q (interview) -Clinical evaluation by Orthopaedic surgeon & MRI	MSD (low back region), regular back pain, duration & frequency, treatment, remain in bed due to back pain, radiating pain, severity	LBP of tractor driving farmer (56%)	Personal characteristics, occupational risks: MMH	Tractor driving farmers report backache more often than non-tractor driving farmer but no significant different on clinical or MRI evaluation
Luoma et al/ 2000/ Finland	Cross sec (n=164)	Machine driver (earth mover, longshoreman)	-Q (self-administered) -MRI	LBP @lifetime, @4 yr & @12mth (+ lumbago, sciatica)	LBP @12mth (74.4%), @4yr (81.1%)	Personal factor, occupational history	-↑ risks of LBP (all types) was found in relation to all sign of disc degeneration -Risks of LBP & sciatica pain strongly affected by occupation -LBP a/w signs of disc degeneration & sciatica pain with posterior disc bulge
Miyamoto et al/ 2000/ Japan	Cross sec (n=153)	Truck	Q (? Interview) -Q with 92 items	LBP (frequency, severity, associated symptoms, relationship with work, treatment & prophylaxis)	LBP @1mth (50.3%)	Personal characteristics, occupational related (work load & environment)	-Vibration is an obvious risk factor for LBP -Significant correlation between personal factors (shortage of spending time with family) & working format (irregular duty time, short resting time, long driving time in a day) and prevalence of LBP. No correlation of occupational factor (workload & work environment)
Mansfield & Marshall/ 2001/ UK	Cross sec (professional, n=13, amateur=105)	Rallying drivers	Q (postal) -adapted from NMQ	MSD directly a/w rallying	Prevalence of LBP averaged across all exposed subject (58%)	Personal characteristics, hx of back injury	-91% at least reported with pain at one body area, more common reported in lumbar spine (70%), cervical spine (54%), shoulder (47%), thoracic spine (36%) -Prevalence of LBP among rally drivers is higher than generally reported for workers exposed to WBV
Battie et al/2002/ USA	Cross sec (n=45 male monozygotic twin pairs)	Twin with history of different pattern of occupational driving	MRI (assessment of disc degeneration i.e. disc height, disc bulging, osteophytes, irregularity in endplates)	LBP@ 12mth (1-7 scale) LBP@ 12mth (0-100 scale) Back pain interfering with daily activities (days)	4.7(2.3) 31(31) 18(61) *Mean(SD)	Personal, occupational physical load (lifting/posture)	Disc degeneration did not differ between occupational drivers and their twin brother
Toren et al/ 2002/ Sweden	Cross sec (n=2579)	Tractor	Q (postal) -modified standardise NMQ	Recall period of LBP @ lifetime/12mth/7dy prior (+ hip symptoms)	LBP @ 12mth 59.0%	Personal & health related (accident, lung related problems), work operation	-Ploughing was the single most time-consuming work operation but it had no influence on the risk of LBP/hip pain -Tractor driving influenced the risk of LBP & hip symptoms

Table 2.8: continued

Author/ Year/ Country	Study design	Types of vehicles	Assessment of MSD		Prevalence/ Incidence of LBP	Confounder	Key reported outcomes
			Methods of investigation	Definition			
Palmer K.T et al/ 2003/ UK	Cross sec (n=22 194) *adequate sample from industry involving exposure to WBV	Car, van, forklift truck, lorry, tractor, bus, loader, train, dumper, excavator, aircraft, off road car, helicopter, armoured vehicles	Q (postal)	Recall period of LBP @ 12mth (pain lasting a day or longer) (+sciatica pain, troublesome)	LBP @12mth 16-24yo (43.3%) 25-34yo (53.7%) 35-44 (54.4%) 45-54 (57.4%) 55-65 (51.2%)	Personal, stress, heavy physical load @ work: lifting	-LBP significant a/w daily lifting of wt >10kg at work -Modest excesses of LBP and sciatica with exposure to WBV in men after allowance for other physical occupational activities, age and psychological risk factor -Burden of LBP in Britain from occupational exposure to WBV is smaller than that attributable to lifting at work
Chen et al/ 2004/ Taiwan (a)	Cross sec (n=1242)	Taxi	-Medical record of standardized lumbosacral spine film	Acquired spondylolisthesis (ASL)	ASL diagnosed at 40 cases (3.2%) & Estimated prevalence: ≤5yr (1.1%), 6-15yr (2.4%), >15yr (7.1%)	Age, anthropometric measures	Taxicab driving > 15yr (OR: 3.4), Age 46-55yo & >55yo (OR:2.6 & 4.8), BMI≥ 25 (OR: 2.2), frequent strenuous exercise (OR: 2.2) significantly a/w higher prevalence of ASL
Hoy et al/ 2005/ UK	Cross sec (n=23)	Forklift truck	Q (interview) -Validated Q (LBP, neck, shoulder)	Pain intensity in the back in the past 12mth	LBP@ 12mth 65.2%	Individual, work environment, psychosocial aspect, lifting & posture demand*assessment using RULA/OWAS (observed & videotaped)	-LBP more prevalent amongst forklift drivers & driving posture in which trunk is considerably twisted or bent forward a/w greater risks -There were indications that WBV acts a/w other factors (not independently) to precipitate LBP
Chen et al/ 2005/ Taiwan	Cross sec (n=1242)	Taxi	Q (self-administrated) -modified NMQ,	Recall period of LBP @12mth	LBP @12mth (51.0%)	Personal characteristics, work related (physical & psychosocial; Job dissatisfaction subscale of the Job Content Q (JCQ)	Occupational risk factors significantly a/w LBP were driving time >4hr, frequent bending/twisting, self-perceived job stress, job dissatisfaction
Bovenzi et al/ 2006/ Italy	Longitudinal (n=598)	Wheel loader, excavator, track type loader, articulated truck, rock crusher, off road car, forklift truck, mobile crane, container stake truck, forklift truck, freight container tractor, garbage truck/compactor, track type loader, minibus, city bus	Q (interview) -VINET Q, modified NMQ: neck, shoulder, low back	Recall period of LBP @ l2mth &@7dy prior (+duration, frequency, radiation, intensity (≥5 Von Korff pain score)/ disability (≥12 RMDS)	LBP@ 12mth& @7dy was greater in drivers	Personal, occupational related (physical load: walking/ standing/posture/ digging/lifting *direct observation), health related	-Individual characteristics (age, BMI) & physical load index (combine MMH & awkward posture) significantly a/w LBP outcomes & psychosocial work factors (job decision, job support) showed marginal relation - professional driving in industry a/w an ↑ risk of work-related LBP

Table 2.8: continued

Author/Year/ Country	Study design	Types of vehicles	Assessment of MSD		Prevalence/ Incidence of LBP	Confounder	Key reported outcomes
			Methods of investigation	Definition			
Okunribido et al/ 2006/ UK (a)	Cross sec (n=394)	Tractor, truck, van, bus, taxi, works driver, police driver, pilots	Q (self-assessment) -validated Q	Recall period of LBP @l2mth &@7dy & previous	LBP @12mth (55.7%), @ 7dy (30.1%) -Based on occupation, highest: Pilot (80.6%) Tractor (43.3%) -Current LBP, highest: Taxi (44.1%) Pilot (41.9%)	Personal, work satisfaction, environment, physical load (posture score & manual handling score)	Combined exposure due to posture & one or both vibration & MMH vs individual exposure to one of the three (WBV, posture, MMH) is the main contributor for ↑ prevalence of LBP
Okunribido et al/ 2006/ UK (b)	Cross sec (n=64)	Van, articulated truck, tripped truck	Q (self-assessment) -validated Q	Recall period of LBP @ l2mth & 7dy prior	LBP@12mth (50.0%) & @7dy (32.8%)	Personal, job satisfaction, work environment *posture, MMH: systematic observation (n=12)	-Transient (LBP < 7dy) prevalent among short haul drivers rather than permeant -Systematic observation of driving activity & MMH is necessary along Q assessment if exposures are to be accurately characterized
Andrusaitis et al/ 2006/ Brazil	Cross sec (n=489)	Truck	Q (? Administration) -validated Q	LBP (i.e. experienced pain, occasional pain & constant pain) related to work activities at define anatomical position (between lower 12 ribs and gluteal fold) not related to trauma/fall	LBP (59%)	Personal characteristics, occupation related issues	The number of working hours was the only variable a/w occurrence of LBP with an average of about one hour longer work time for those have LBP
Okunribido et al/ 2007/ UK	Cross sec (n=80)	Bus	Q (self-assessment) -validated Q	Recall period of LBP @ l2mth & 7dy prior	LBP@ 12mth (59.0%) & LBP@ 7dy (23.7%)	Personal, job satisfaction, work environment *posture, MMH: (observation n =12 completed round trip 1hr 21min to 1hr 41min)	-Transient & mild LBP (not likely interfere with work or customary level of activity) prevalent among drivers & need ergonomic evaluation of driver's seat -Drives w LBP (older, heavier & lifted medium loads) but not significant
Tamrin et al/ 2007/ Malaysia	Cross sec (n=760)	Bus	Q (self-administered with guidance) -modified NMQ	Pain @ 12mth according to area i.e. neck, shoulder, elbow, arm, upper back, lower back, hip, thigh, knee, leg	Prevalence of lower back (60.4%), neck (51.6%), upper back (40.7%)	Personal characteristics, Occupational related (posture; OWAS & psychosocial; POMS)	Combination of risks lead to high ↑ of LBP among Malaysian bus drivers
Virtanen et al/ 2007/ Finland	Cross sec (n=150)	Train drivers	-Clinical assessment + clustering of symptoms based on latent class analysis (LCA) -Lab Investigation (genetic analysis)	LBP @ 3mth (+ intensity, duration, frequency)	Not reported	Not reported	-The number of individual belonging to IDD (Intervertebral disc disease)-phenotypes significantly higher among train drivers (42%)

Table 2.8: continued

Author/Year/ Country	Study design	Types of vehicles	Assessment of MSD		Prevalence/ Incidence of LBP	Confounder	Key reported outcomes
			Methods of investigation	Definition			
Szeto et al/ 2007/ Hong Kong	Cross sec (male, n=404, female=77)	Bus	-Q (interview) *Chinese version of standardized NMQ -physical assessment (lumbar spine, hand grip strength, sit & reach test, observation of standing & sitting posture)	WRMD @ 12mth	Neck, back & shoulder pain had highest prevalence @12mth ranged from 35% to 60%, discomfort related to bus driving 90%	Personal characteristics, work related risk	Occupational factors of prolonged sitting and anthropometric mismatched were perceived to be most related with musculoskeletal discomfort
Tiemessen et al/ 2008/ Netherlands	Longitudinal (n=571)	Lawn moving, wheeled loader, excavator, lorries, dumpers, steamroller, tractors, bulldozer, mobile crane, boats, asphalt machine	Q (Self-administered) -VINET, NMQ, VAS	Recall period of LBP @l2mth, @driving related, @intensity VAS score ≥ 5, @ disability RMDS score ≥ 12	LBP@12mth (60.9%) @diving related (31.7%), @intensity (8.5%) & @disability (5.7%)	Individual, Work related (heavy physical load, lifting, posture; RMDS, *physical risks index rating, work satisfaction* psychosocial index)	Depending on LBP outcome various individual factor (marital status, back trauma, smoking) & work related (previous job with heavy physical load, lifting, bending, physical risk index) relates significantly to onset of LBP
Miyamoto et al/ 2008/ Japan	Cross sec (n=1334)	Taxi	Q (? Self-administered) -Validated Q, VAS,	Recall period of LBP @1wk	LBP @1wk (20.5%)	Personal characterises, occupational related (work condition & environment; RMDS)	Risk factor for LBP (history of LBP, suffering from fatigue, disease other than LBP, smoking)
Palmer et al/ 2008/ UK	Case control (n=252 including n=185 professional driver vs control n=820) *referred for MRI for lumbar spine	Car, lorry, bus, forklift truck, ambulance, loader, tractor	-Q (postal) -MRI	History of LBP (+sciatica), disability (RMDS),	-Median duration of the current episode of LBP was 1.0 (IQR 0.5-2.2) years -79% reported with sciatica pain	Personal characteristics, work related (physical, psychosocial)	-Strong association with poor mental health & belief in work as a causal factor for LBP & occupational sitting ≥ 3hr while not driving -Association also with taller statue, consulting propensity, BMI, smoking, fear avoidance belief, frequent twisting, low decision latitude, low support at work -At population level WBV is not an important cause of LBP referred for MRI
Bovenzi/ 2009/ Italy	Prospective cohort (n=537)	Earth moving machine, articulated dumper, off road car, forklift truck, freight container, mobile crane, garbage truck/ compactor, bus	Q (Interview) -VINET, NMQ	Recall period of LBP @l2mth, @intensity NRS score >5, @ disability RMDS score ≥ 12	LBP@12mth (36.3%), @intensity (24.6%) & disability (19.2%)	Personal, occupational related (physical load/walk/stand/sit/ non-neutral posture/lifting), psychosocial (job decision/support/satisfaction)	-Physical workload but not psychosocial environment was significantly a/w occurrence of LBP over time
Rozali et al/ 2009/ Malaysia	Cross sec (n=159)	Military Armoured Vehicles	Q (self-administered) -Validated NMQ	Recall period of LBP @12mth	LBP @12mth (73.6%) higher in tracked armoured vehicles (81.7%) vs wheeled (67.0%)	Personal characteristics, psychological; GHQ, occupational (posture, manual lifting)	Driving in forward bending sitting posture & WBV exposure at x-axis were significant risk factors for LBP among military armoured vehicles

Table 2.8: continued

Author/ Year/ Country	Study design	Types of vehicles	Assessment of MSD		Prevalence/ Incidence of LBP	Confounder	Key reported outcomes
			Methods of investigation	Definition			
Bovenzi/ 2010/ Italy	Prospective cohort (n=202)	Earth moving machine, articulated dumper, off road car, forklift truck, freight container, mobile crane, garbage truck/ compactor, bus	Q (Interview) -VINET, NMQ	Recall period of LBP @l2mth, @intensity NRS score >5, @ disability RMDS score ≥ 12	LBP@ (38.6%), @intensity (16.8%), @disability (14/4%)	Personal, occupational details (physical load: walk/stand/sit/ non-neutral posture/lifting), psychosocial (job decision, support, satisfaction)	-Physical work load was significant predictor of LBP over follow up period -Perceived psychosocial work environment was not a/w LBP
Alperovitch et al/ 2010/ Israel	Cross sec (n=384)	Bus	Q (interview) -standardized NMQ	Recall period of LBP @12mth	LBP @12mth (45.4%)	Personal characteristics, ergonomic, psychosocial stressing factor	Work related ergonomic & psychosocial factors showed a significant association with LBP in Israeli professional urban bus driver
Samuel et al/ 2012/ Nigeria	Cross sec (n=1406)	Taxi	Q (? Administration)	Recall period of WRMD at 4 body segment neck, wrist, back (upper, middle, lower), buttock @12mth & 7dy	LBP @12mth (30.6%) & @7dy (31.6%)	Personal, work related; Participatory ergonomic intervention approach (PEIA) & work analysis (ergonomic, workspace)	General experienced of low back & upper back and other explainable musculoskeletal stress area i.e. wrist, buttock, feet & neck -Level of discomfort more pronounced among long distance business driver
Nahar et al/ 2012/ Bangladesh	Cross sec (n=246)	Professional car driver	Q (interview) -Q had 14 items including LBP	Recall period of LBP @12mth	LBP @12mth (78%)	Personal characterises, work related risk	The risk factors for LBP were age, daily & cumulative driving (long working hr) & statue (BMI)
Mozafari et al/ 2014/ Iran	Cross sec (n=346)	Truck	Q (self-administered) -NMQ	Recall period for MSD including lumbar area @ 7dy & 12mth	MSD revealed for (78.6%) with most common symptoms at neck, lumbar, knee	Personal characteristics, physical load at work (uncomfortable posture & static muscle load)	Musculoskeletal disorder showed statistically significant with work duration, age and BMI (P<0.001)
Knox et al/ 2014/ USA	Retrospective database analysis (n=8 444 167 person-years)	Military vehicles	Data search from US Defence Medical Epidemiology database	LBP classified using International Classification of Disease (ICD)	LBP incidence rate 54.2 per 1000 person-years	Personal characteristics (sex, race, rank, service, age, marital status)	Motor vehicle operators have a small but statistically significant ↑ rate of LBP compared to matched control population
Noda et al/ 2015/ Sri Lanka	Cross sec (n=200)	Three-wheeler	Q (? interview) -Validated occupation specific Q	Recall period of LBP @ 4wk	LBP @4wk (15.5%)	Personal characteristics, psychological; perceive stress score (PSS), occupational risks	LBP is common among drivers of three-wheeler in Sri Lanka with long hours and two stroke engines were significantly a/w LBP
Fadhli MZK et al/ 2016/ Malaysia	Cross sec (n=96)	Bus	Q (? Administration) -modified NMQ	Pain at the lower back of the body	LBP (74.0%)	Personal characteristics, occupational risks (ergonomic)	-Working hr per week, workspace condition & body posture a/w LBP -The ergonomic risk factors exposed the drivers to higher level in generating LBP

?, uncertainty; Q, Questionnaire; NMQ, Nordic Musculoskeletal Questionnaire; a/w, associated with; hr, hours; @, at;

2.3.4 Societal Impact toward Professional Drivers

Several published critical reviews concluded that there is strong epidemiological evidence to support the relationship between occupational exposure to WBV, LBP and back disorders. However, whether this exposure is only a modest or substantial risk factor for the onset and recurrence of LBP is still a matter of debate. However, the only diagnosis related to occupational mobility and early retirement due to permanent disability was disorders of the back and spine (Siebert, Rothenbacher, Daniel, & Brenner, 2001). There are four European Union countries that have decided to recognize LBP and certain spinal disorders as an occupational disease and subsequently provide a compensation scheme for these illnesses, namely Belgium (1978), Germany (1993), Netherlands (1997) and France (1999). About 2 % of the US workforces are compensated for back injuries each year (Andersson, 1999)

LBP has enormous impact on individual, families, communities, government and business throughout the world (Hoy et al., 2010). Whereas episodes of acute and subacute attacks are manifestations of the disease at early stage, chronic LBP with severe disability characterize late stage of disease (Krismer & van Tulder, 2007). Most episodes of LBP subside after a couple of weeks and most individuals will return to work within one week, with 90% returning within two months (Krismer & van Tulder, 2007). Individuals who did not recover within 3 months, unfortunately will lead to slow recovery process (Andersson, 1999). Most patients with disability for more than 6 months will not return to work as once chronic LBP has established the prognosis is poor, with many patients continuing to have pain and disability for more than 1 year after initial episode (Diamond & Borenstein, 2006). The estimated rate of recurrence within one year ranges from 24% to 80% (Hoy et al., 2010).

Chronic LBP can cause significant functional disability and commonly become frustrating for both patients and physician to cope with and treat (Diamond & Borenstein, 2006). People with physically or psychologically demanding jobs may have more difficulty working when they have LBP, and so lose more time from work (Waddell & Burton, 2001). Chronic LBP leads to increase in disability and sick days as well as increases in medical costs to society (Shemory et al., 2016).

The alarming part of LBP in occupational setting must be seen against the high background prevalence and recurrence rates of low back symptoms, and to lesser extent disability among the adult population (Waddell & Burton, 2001). Indirectly or directly the symptoms of low back pain might influence people with certain types of occupation to change their job to another, which has less exposure towards a particular risk at work place. However, changing jobs might not be the only solution. The non-occupational and psychosocial issues are important so it may be questionable to what extent occupational interventions can realistically be expected to reduce the societal impact of low back pain (Waddell & Burton, 2001). Having said that, the occupational risks factors is the component that can be manipulated and modified to suit the level which is deemed to be safe for the worker. Efforts are still needed to evaluate the occupational risks involvement, because the reduction in exposure to these risk factors might contribute to the improvement of LBP.

2.4 Healthy Worker Effect

2.4.1 Definition

William Ogle, 1885, is believed to be the first person to described healthy worked effect (HWE) which was published in the appendix of the Registrar General's report on mortality in England and Wales (Heederik, 2006). It refers to the observation that the working population is healthier than the general population. William Ogle identified two types of natural selection processes responsible for this phenomenon; the first works at the time of hiring, and the second works at the time of employment. The first natural selection process selectively attracts or rejects new workers depending on physical demands and health status requirements of the job. The second selection process forces people to leave the industry because their health is too much impaired for the job they are in. In 1976, McMichael AJ proposed a name for this phenomenon as HWE (Shah, 2009). HWE were referred to as a consistent tendency of the actively employed person to have more favorable mortality experience than the population at large. HWE is not only reflected in terms of lower mortality, but also lower morbidity (frequency and severity rate of illness) and possible longer life expectancy (Wen & Tsai, 1982).

2.4.2 Components of Healthy Worker Effect

The components of HWE can be classified into (i) healthy hire effect, (ii) healthy worker survivor effect, (iii) time since hire, and (iv) beneficial effect of work (Shah, 2009). Each term is further elaborated and defined below:

1. Healthy hire effect refers to employer right to reject certain people for employment because of their physical disabilities or poor general health. An employer will exclude those obviously at high risk. Person selection may also be influenced by their habits and physical conditions such as weight, smoking or alcoholism.
2. Healthy worker survival effect refers to people who do not have strong motivation to work because of health problems and do not present themselves for employment (self-selection). They generally change jobs frequently or retire early. They change their job for different reasons including health issues.
3. Time-since-hire refers to the length of time the population has been followed. HWE is a characteristic of an actively employed workers. Incomplete follow up of out-migration section of the cohort could result in failure to track every individual to determine their vital status. Reduction in health status could occur without any relation to exposure.

4. Beneficial effect of work refers to a worker’s improved access to healthcare and routine disease screening.

HWE can be expressed as SMRs (standardized mortality ratios) and influenced by the following three factors: (i) selection bias, (ii) improved socioeconomic status, and (iii) the conventional way of calculating SMRs (Wen & Tsai, 1982). An examination of these three factors shows that selection of employability is probably the most significant factors for the HWE. Secondly, improved socioeconomic status because of employment has been shown to lower mortality (Bartley & Owen, 1996). Socioeconomic status makes a large difference to the impact of illness as it retains the ability to remain in paid employment and this impact increases as unemployment rises.

2.4.3 Impact of Healthy Worker Effect toward working population

Healthy Worker Effect (HWE) had influence on different types of occupation. In Denmark, electricians had lower mortality rate (rate ratio, 0.60; 95% CI, 0.52-0.69) compared to the general population. However, people leaving employment had increased mortality rate (1.90; 1.50-2.40), while mortality rate was comparable to the general population after three or more year of lag time (Thygesen, Hvidtfeldt, Mikkelsen, & Brønnum-Hansen, 2011). Mortality rates among workers who leave work (inactive workers) are higher than among active workers because some workers leave because they are ill (Steenland, Deddens, Salvan, & Stayner, 1996). Another study among workers of potato processing industry found that they showed no chronic respiratory effect following exposure to organic dust despite the levels of exposure to endotoxin found in this industry reported to be associated with decrease in lung function in other occupational settings (Zock, Heederik, & Doekes, 1998). A likely explanation for not detecting apparent effects might be that many symptomatic workers drop out of this industry a few years after starting the job, a phenomenon suggestive of HWE. Furthermore workers who had been employed for more than five years had less respiratory symptoms, a higher lung function and less atopy (Zock et al., 1998). A longer period of follow-up as well as a longer time selection criterion, lead to the subjects having more working experience which likely to have reduced the mortality (Chen & Seaton, 1996). Moreover, trend toward lower exposures to endotoxin in longer term workers may suggests that job rotation also plays a part in this process (Zock et al., 1998)

HWE noticed to be more visible in occupational health studies among manual workers in comparison to non-manual workers. People in manual labor must be "healthier" to remain employed, in contrast to people working in managerial, professional or clerical work (Bartley & Owen, 1996). Thus, sedentary job has a statistically significant protective or neutral effect in relation to LBP, whereas having a heavy physical job constitutes a statistically significant risk factor (Hartvigsen, Bakketeig, Leboeuf-Yde, Engberg, & Lauritzen, 2001). The healthy worker survivor effect was found to be related to disorders of the back and spine a common predictor of both occupational morbidity (RR 1.17, 95% CI 1.04 to 1.32) and early retirement (RR 1.50, 95% CI 1.20 to 1.88) (Siebert et al., 2001). HWE also causes the point prevalence of LBP in the sedentary group to become inflated over time because of workers with longstanding LBP changing from heavy physical to sedentary work (Hartvigsen et al., 2001).

2.4.4 Impact of Healthy Worker Effect towards epidemiological study

There are many observed effect of healthy worker towards epidemiological study. Most studies indicate that healthy worker effect will reduce the association between exposure and outcome by an average of 20-30% (Shah, 2009). HWE also can be a source of selection bias, whereby errors occurred due to systematic differences in characteristics between those selected for study and those not selected. The selection bias occurred due to effect of HWE during the initial hiring into workforce and subsequent factors which influence continuing employment (Shah, 2009). HWE generally become the negative confounder for employment status observed via analysis of trends between cumulative exposure and mortality (Steenland et al., 1996), as caused by percentage of inactive relative to active person-time is higher in low categories of cumulative exposure. Apart from that, HWE also diminished possibilities to detect associations between occupation and disc degeneration because people who developed back problems may select a less strenuous occupation (Luoma et al., 2000).

2.4.5 Summary

The involvement of HWE especially studying the impact of WBV exposures among professional drivers does influences the outcomes in so many ways. The two main components of HWE which are the healthy hire effect and healthy worker survival effect contributed in the selection of drivers as a respondent. Thus, eventually the outcomes might be distorted as only the healthy drivers confined to the job and masking the real side effect of the WBV exposures.

CHAPTER 3: METHODS AND MATERIALS

3.1 Study Design

This is a cross sectional study involving various types of vehicular drivers employed by selected companies in the state of Sabah. Data collection started in November 2011 till December 2012. The study design selected appropriately to meet the requirement of targeted objectives of this study.

3.2 Study Area

The study was conducted in state of Sabah. Sabah is the second largest state in Malaysia that covers a land area approximately 329,750 sq km. It consists of five major divisions and further subdivided into 24 districts. Major towns are connected through network of roads. Sabah is generally mountainous and hilly in nature whereby this geographical distribution highly influences the road networking and coverage. West Coast Division consists of Kota Belud, Tuaran, Kota Kinabalu, Penampang and Ranau districts. The data collection for this study were concentrated at the district of Kota Kinabalu, Penampang, Putatan and Kota Belud. These areas are highly accessible via road transportation and become the center of various government facilities. Being the most developed part of Sabah, the interconnecting roads in the West Coast Division are mostly sealed with asphalt. Generally, the roads in Sabah are undergoing extensive development. However, there are still areas covered with gravel and rough road surfaces especially in the suburban and rural area. The map of Sabah showing the location of the West Coast Division and pictures of the road condition covering the district of Kota Kinabalu, Penampang, Putatan and Kota Belud is attached in APPENDIX B.

3.3 Study Populations

The study population for this study consisted of drivers working with selected companies in Sabah. Companies from both government and private sectors were identified and invited to participate in our study. Only companies that gave their commitment to participate were taken as center of data provider.

The participating companies were from Taxi and Limousine Association of Kota Kinabalu International Airport, Kota Kinabalu City Hall, University Malaysia Sabah, Sabah State Health Department, Sabah Road Transport Department, Fire and Rescue Department, Sabah Education Department, Sabah Civil Defense Department and The Malaysian Armed Force (Paradise Army Camp based in Kota Belud Sabah).

The Types of vehicles operated by the drivers were classified as MPV (Multi-Purpose Vehicles), Public Transport (Bus), Ambulance, Fire Fighter Truck, Lorry/Truck, Saloon Car, Garbage Compactor/Truck and SUV (Sport Utilities Vehicle). The operational definition for each types of vehicles are illustrated in **Table 3.1**. The images of the types of vehicles involved in our study are attached in APPENDIX C.

Table 3.1: Operational Definition for Types of Vehicles

Classification of Vehicles	Operational Definition
Ambulance	A specially equipped motor vehicle for carrying sick or injured person.
Fire Fighting Truck	A specially equipped motor vehicle used to assist in fighting fires
Garbage Truck	A specially equipped motor vehicle used during collection of disposal.
Lorry/Truck	Any of various conveyances used for transporting materials.
Multipurpose Vehicle (MPV)	Any large motor vehicle that can be driven in various conditions and usually can hold eight passengers.
Public Transport (Bus)	Any large motor vehicle having long body and equipped with seats or benches for passengers.
Saloon Car	A motor vehicle with seats for four or five people, two or four doors, and a separate area at the back for bags, boxes and cases.
Sport Utility Vehicle (SUV)	A motor vehicle with four wheels, usually propelled by an internal combustion engine.

The companies that participated in this study were mostly operated under the government organization. Only the Taxi and Limousine Association of Kota Kinabalu International Airport operated under private sector. Most drivers posted in this various companies hold their post as permanent worker. Their work schedule varies and some of them have to perform outstation duty as required by their management. Their usual route of travelling located at west coast division, but they may also need to travel outside this region if commanded for outstation duty. The drivers usually assigned to drive one types of vehicle but at certain time they were also required to drive other types of vehicles depending on their organization needs.

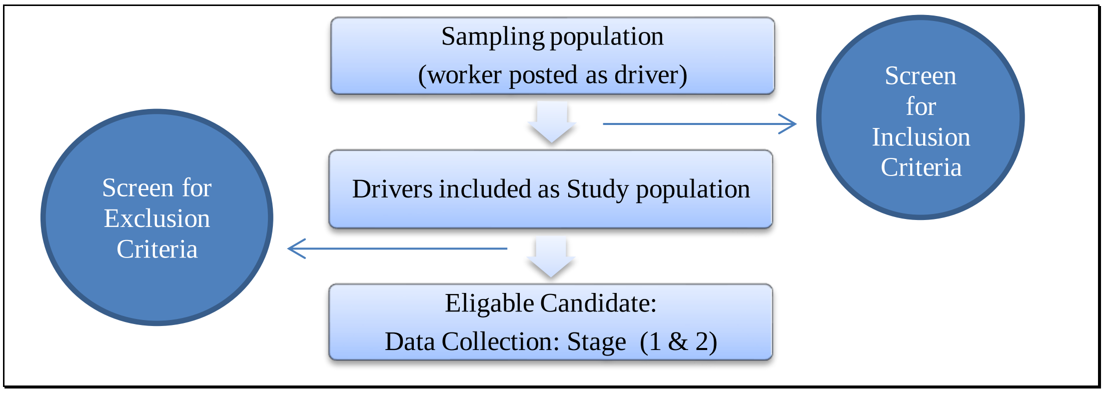
3.4 Sample Size

The estimate of sample size requirement was calculated using Epi Info software version 3.5.1. The calculation was based on estimated prevalence of LBP among control group of 64% (Bovenzi & Hulshof, 1999a), Odd Ratio of 2.2 (Bovenzi et al., 2006b), alpha set as 0.05 and power of 80%. Based on these parameters, the sample size required for this study is 282 subjects. Participants who volunteer to take part were screened using exclusion and inclusion criteria. Participants who did not fulfill the requirement were eliminated at the beginning of this study. Hence no drop-out of respondents were anticipated during recruitment stage.

3.5 Sampling Procedure and Recruitment

The convenient sampling method was adapted throughout implementation of this study. Selection of companies via randomize methods was difficult to exercise as some companies have strict regulations and not allowing non-employee to ride along with their vehicles. Furthermore, the private companies preferred not to participate as worried of the outcome and expecting that the researcher come from the enforcement body trying to audit in the way they are managing their worker. The governmental statutory bodies were more willing to give their cooperation. Cooperation and support from the higher management needed, as it is going to be the pushing factor for the driver employed by their companies to participate. Drivers also required being to be in move and hardly remain in one place for a long duration of time. This has caused difficulty to the researcher to confront them. Thus, selection of drivers was limited to those available during scheduled data collection time and depended solely on their willingness to participate on voluntary basis.

Other than that, limited time and financial resources forced us to confine the area for data collection within our accessibility. The West Coast Division of Sabah were purposely selected in view of its accessibility in term of road transportation as well as it being the center of major and various facilities. The other divisions in Sabah are located further away and more time will be needed if they were to be included in this study. Invitations in the form of formal letter were extended to companies available in West Coast Division known to operate a wide variety of vehicles. Only companies that agreed to participate in the study were taken as center of data collection. The steps taken in sampling procedure during selection of the study participants are shown in Figure 3.1. All drivers working in the participating companies were taken as the sampling population. All drivers who fulfilled the inclusion and exclusion criteria were taken as source for eligible candidates. The process of sampling procedure and recruitment were according to the flow chart as illustrated in Figure 3.1.



Stage 1: Face to face interview using questionnaire
Stage 2: Field measurement and monitoring of WBV exposure and observation of posture adopted while driving

Figure 3.1: Flow Chart on Sampling Procedure and Recruitment

A Series of visit to all center of data collection were scheduled accordingly. Recruitment of driver was conducted for each center until the targeted number achieved. Participation of drivers as candidate was based on their availability during the data collection schedule and on voluntary basis. They must also fulfill the inclusion and exclusion criteria as listed below.

3.5.1 Inclusion Criteria

The inclusion criteria include job title or job description as drivers, and they must have been employed for the minimum period of one year at their current post and have accumulated 20 hours of driving per working week.

3.5.2 Exclusion Criteria

The exclusion criteria include confirmed diagnosis of medical and surgical conditions which predispose to specific causes of low back pain (certified by attending doctors or on specific treatment) and previous history of back trauma.

3.6 Trial Registration and Ethical Approval

Ethical approval for this study was obtained from University Malaya Medical Centre, Medical Ethical Committee with reference no of MEC Ref. No: 884.7. One of the ethical issues raised was confidentiality with regards to participant having to reveal their medical condition and their suffering from LBP. The Drivers might have stigma from the possibility of being terminated from their current job due to their medical illness if the employer became aware of their health problems. To overcome this issue, the interview was conducted on one to one basis and it was emphasize to the respondents that all information gathered in the study will not be revealed to their superior.

3.7 Data Collection

Data collection process was commenced starting from 1st November 2011 till 31st December 2012. Initially completion of data collection was estimated in June 2012 but due to some technical problems it delayed until end of the year. There were nine center of data collection based on the companies that agreed to participate. As the location of the participating companies scattered in many locations in West Coast of Sabah, a schedule of visits were arranged prior to data collection. Each company received notifications via a formal letter and a courtesy phone call one day before the arranged visit. Data in this study were collected from face to face structured interview using an adapted questionnaire. Objective measurements of WBV were conducted using accelerometer and direct observation of the posture adapted by the drivers.

3.7.1 Face to face Interview

The first session of the data collection was the face to face interview conducted by the researcher. The session lasted about 30 - 45 minutes for each participant. Each of data collection center provided a private room for the researcher to conduct interview session. The drivers were interviewed inside the private room, one driver per session to maintain privacy and to ensure their confidentiality. The researcher conducted the face to face interview following the structured questionnaire that developed earlier on. The interview process was conducted in *Bahasa Malaysia*. This language is well communicated by all the participants with good language proficiency and understanding. Translation to other native language was not required.

3.7.2 Objective Measurement of Whole Body Vibration

The second session was the actual field measurement and monitoring of WBV and observation of posture adapted by drivers that was conducted simultaneously. The researcher tagged along with the driver while they are performing their daily routine activity. Monitoring of WBV was conducted to all drivers and they were required to follow their normal route and drove the types of vehicles that they currently operated. The monitoring was recorded for three times taken five minutes each. First reading was initiated within first ten minutes from the time the drivers started their journey. The second reading subsequently following the next ten minutes and the third reading was the remaining ten minutes of the journey. The whole session lasted about 30 minutes for each driver per each vehicle.

The procedure for measurements of WBV strictly followed the standard of measurement recommended by the International Standard ISO 2631-1, 1997 (ISO, 1997). The Standard recommends three types of position for measurements which is seating, standing and recumbent. Adaptation of seating position require the placement of the sensor either on the supporting seat surface beneath the ischial tubersosities. If the sensors were to be placed on the seat back, they should be placed in the area of principal support of the body. If they were to be placed on the feet, they should be placed on the surface on which the feet are most supported. Since seating is the most appropriate position for assessment while driving, this was the only position adapted in this study.

The transducer or accelerometer used to measure the acceleration was placed on the supporting seat surface. The placement of accelerometer in this position allowed it to be constantly in place and directly in contact with the drivers. The WBV monitoring setup is illustrated in APPENDIX D.

3.7.3 Subjective Observation of Posture (While Driving)

Direct observation of adapted posture was conducted concurrently while performing the measurement of WBV. The adapted posture was classified into posture against backrest, posture straight, posture bent, posture twisted, and posture bent and twisted. Score were given in percentage, based on the time spend in minutes by the driver on the types of posture above. The time spend in minutes then converted into percentage, which able to identify the most adapted posture. The observation times were throughout the journey during the monitoring of the WBV. It took roughly around 30 minutes for each driver. Please refer in APPENDIX E the form used for data collection.

3.8 Study Instruments

3.8.1 Questionnaire

Structured questionnaire prepared only in English language. The questionnaire was divided into five main sections. Section one was on participant's general information (i.e. sociodemographic, lifestyles and anthropometric measurement). Section two was on work details information (i.e. driving exposure, types of vehicles, job history). Section three was on health complaint and assessment (i.e. past medical and surgical history, trauma at back region, presence of MSD other than back region, outcome measures of LBP, Red Flag characteristics). Section four was on objective measurement of WBV (i.e. data on frequency weighted acceleration (x, y, z-axis) of r.m.s and VDV, vector sums, CF). Section five was on subjective measurement of adapted posture (i.e. scoring system given in percentage for adapted posture). Answers to most of the question especially the continuous variable were collected based on information's reported by the respondents. The data were classified as required for further analysis. Some of the questions used open ended methods, whereby the subject need to answer yes or no. A copy of the standardized questionnaires is attached in APPENDIX E.

3.8.1.1 Health Complaint and Assessment

In health complaint and assessment section of the questionnaire, the outcome measure of LBP was evaluated by adapting the modified version of Nordic Musculoskeletal Questionnaire (NMQ). The modified version included eleven sets of question to be answered by the participants. All questions are close ended question that require the respondents to answer yes or no to each set of question. The assessment of LBP include question on the location of pain (the diagram showing the anatomical location of back region were attached as shown in Appendix F), age of initial onset of back problems, history of hospitalization, history of job changes (temporarily also counted), occurrence of LBP in the in the past within 12 months prior, four weeks prior and post driving. The diagram shown to the drivers as a guide for the drivers to identifying the exact location of the back area. Only drivers pointed the occurrence of pain at the correct area were taken as case of LBP. The diagram used as a tools to help the drivers to visualize and identified the exact location of the back area.

Apart from that they were evaluated for the past 12 months if the pain they experienced troubled them from doing normal work (home or away from home), pay a visit to any health care provider, ever took medication and ever take medical certificate. The Red Flag Characteristic was in cooperated as extension for the assessment of LBP among the participants. The assessment was meant to screen participants with high suspicion of having serious pathology. It consists of 17 set of symptoms and developed as close ended questions with yes or no answer.

a) Nordic Musculoskeletal Questionnaire (NMQ)

Adaptation of NMQ as part of assessment for the outcome measures of LBP was selected for use in this study because this questionnaire was commonly adapted by another researcher. However, the standardized format was modified to suit the need of this study.

In a clinical set up, assessment of LBP involved certain steps that are able to determine the exact diagnosis via history taking, physical examination and supported with laboratory test and/or radiographic evaluation. However, in a research environment, a simplified screening tools for evaluation and assessment of the LBP is needed to obtain the intended information. Usually a single structured questionnaire is formulated, whereby the format of the structured questionnaire should be less complicated, easy to understand and can be administered in short time (Dickinson et al., 1992). The simplified questionnaire ensures easy understanding from the groups of subjects to be able to answer all questions.

NMQ is the standardized questionnaires for the analysis of musculoskeletal symptoms in an ergonomic or occupational health context (Kuorinka et al., 1987). It serves as screening instrument for musculoskeletal pain and related events not only in occupational studies but also general population (Dawson, Steele, Hodges, & Stewart, 2009). The questionnaires provides means to measure the outcome of epidemiological studies on musculoskeletal disorders, however it is not meant to provide a basis for clinical diagnosis (Kuorinka et al., 1987). It originally consists of a general questionnaire and a more detailed body part-specific questionnaire. The general questionnaire shows a body map diagram divided into nine anatomic regions and asks about the presence of physical troubles including ache, pain, and discomfort (Kaewboonchoo et al., 1998). These anatomical regions (viewed from the back) are divided on the basis of two criteria: regions where symptoms tend to accumulate, and regions which are distinguishable from each other both by the respondent and a health surveyor (Kuorinka et al., 1987). There are nine body mapping for symptom sites being neck, shoulders, upper back, elbows, low back, wrist/hands, hips/thighs, knees and ankles/feet. The questions used are forced choice variants intended to reflect specific characteristics of work strain in the frequency of responses to the questionnaires (Kuorinka et al., 1987) which means the respondents can give specific response such as yes or no to the questions given. The questionnaire may be either self-administered or administered by an interviewer (Dawson et al., 2009; Kuorinka et al., 1987).

NMQ is accepted as a suitable tool for application in a wide diversity of workplace and could accommodate very large number of workers in a study very quickly and cheaply (Dickinson et al., 1992). The reliability of the questionnaires has been shown to be acceptable (Kuorinka et al., 1987) and able to produce reliable data with regards to onset, prevalence and consequences of musculoskeletal pain in an educated occupational cohort (Dawson et al., 2009). In Malaysia one study conducted among bus drivers (Tamrin et al., 2007) and another study involving the military armoured vehicle drivers (Rozali et al., 2009) adapted the NMQ for assessment of LBP.

b) Red Flag Characteristics

The exact diagnosis of work related LBP might be difficult to assessed because there is little evidence that physical loading in modern work causes permeant damage (Waddell & Burton, 2001). As supported from the review conducted very minimal benefit derived for the confirmatory test even proceeded to perform physical examination and diagnostic imaging. Furthermore, there are no pathognomonic features that can distinguish vibration-associated back pain from other causes of back pain (Pope et al., 2002). Thus, a mechanism to eliminate LBP that may arise from serious spinal pathology should be considered.

The red flag characteristics provide a unique weighted "red flag" hierarchy list of findings that should raise suspicion of serious pathology in patients with back pain (Greenhalgh & Salfe, 2009). This approach adapted the diagnostic triage to enable the practitioner to identify patients who have a high index of suspicion for serious spinal pathology. Red flags have been used by doctors since 1949 and more recently very popularly utilize by physiotherapists (Ferguson, Holdsworth, & Rafferty, 2010). The 'Red flags' are signs in addition to LBP and they are listed below;

- Age of onset less than 20 years or more than 55 years
- Recent history of violent trauma
- Constant progressive, non-mechanical pain (no relief with bed rest)
- Thoracic pain
- Past medical history of malignant tumour
- Prolonged use of corticosteroids
- Drug abuse, immunosuppression, HIV
- Systemically unwell
- Widespread neurological symptoms (including cauda equina syndrome)
- Structural deformity
- Fever
- Widespread neurological deficit
- Lower limb weakness
- Persistent severe restriction of lumbar flexion
- Night pain
- Positive cough/sneeze
- Unexplained weight loss

If any of the above symptoms were present together with low back complaints, further investigation (according to the suspected underlying pathology) may be require excluding a serious underlying condition, e.g. infection, inflammatory rheumatic disease or cancer. Adaptation of the red flag characteristic as assessment tools can help researchers to raise their index of suspicion to eliminate LBP cases with systemic illness manifestation or with known underlying pathology from their study.

3.8.2 Accelerometer

The instrument used for measurement of WBV was from the Quest Technologies, which is a design, manufacturing and marketing company with distribution in over 50 countries worldwide. The company has built a strong reputation for rugged and reliable instrumentation and software systems that monitor and evaluate occupational and environmental health & safety hazards including noise, vibration, heat stress, indoor air quality and toxic/combustible gases (QuestTechnologies, 2008a). The company is a registered company with ISO 9001:2000 and accredited for calibration lab 1SO 17025 (QuestTechnologies, 2008b).

The instruments used in this study inclusive of the Human Vibration Analyzer model V1-410, seat pad accelerometer, USB cable, accelerometer cable and Quest Suite Professional II software. The accelerometer is located in the middle and enclosed inside the disk-shaped seat-pad object. The human vibration analyzer model V1-410 and Quest Suite Professional II software is an integrated system.

The Quest Suite Professional II software (QSP-II) helps to set-up the VI-410 with the appropriate mode, range, calibration, profile, filter, and logged items. This software is able to retrieve data from the instrument, view the measured results and print out customized reports (QuestTechnologies, 2008a). Data from VI-410 can be transferred and downloaded to the lab top connected through a USB Cable.

Before the vibration study was conducted the pre-calibration performed as recommended in the manual. Calibration is needed as the instrument can be affected by changes in altitude, barometric pressure, and humidity. Depending on where the VI-410 is stored and where the measurements took place, these factors can change the instrument's readings. Field calibration for the VI-410 can be conducted using two methods i.e. by measurement - this entails connecting a calibrator to the VI-410 and turning it on for the output to stabilize. Once the desired frequency and amplitude has been reached, this is entered into the meter (or in QSP-II) and by sensitivity - the process of verifying the instrument's calibrated measurement indicated on the instrument's certification papers. The instrument used for this study were calibrate by inputting values from the instrument's calibration card/certificate.

3.9 Measurement and Assessment of Vibration Exposure

Basic and additional evaluation were both reported for assessment of the WBV exposures. The basic evaluation involved the measurement of frequency weighted root-mean-square (r.m.s) of acceleration expressed in meters per second squared (m/s^2) and additional evaluation, the VDV also known as Fourth Power Vibration Dose measurement of frequency weighted root-mean-quad (r.m.q) expressed in meters per second to the power of 1.75 ($m/s^{1.75}$).

As mention earlier measurements for this study were only conducted at seated position. The basicentric axes of human body in a seated position has three direction which is the back-to-chest direction (x axis), right-to-left direction (y axis) and vertical direction (z axis) as illustrated in Figure 3.2. Frequency-weighted accelerations expressed in a_{wx}, a_{wy} and a_{wz} were obtained from one third octave band frequency spectra (1-80 Hz) and weighted using the ISO 2631-1 weighting factors of *Wd* for x-axis and y-axis, *Wk* for z-axis (ISO, 1997).

The used of vibration total value or vector sum expressed in a_{vs} and a_{vq} for weighted acceleration in r.m.s and r.m.q were obtained and proposed to use as an evaluation in respect to health and safety over the usage of predominant axis.

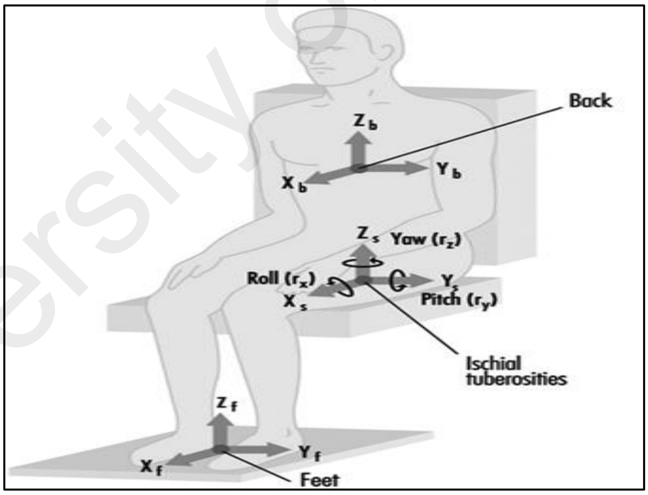


Figure 3.2: Basicentric Axes of Human Body in a Seated Position

The action or limit value is almost always 8 hours as this is the typical duration of workday. However, the actual WBV exposure times can often be less than 8 hours. Therefore, we expressed the vibration vector sum (total value) of the frequency weighted (r.m.s) accelerations (a_{vs}) in m/s^2 for duration of less than 8 hours as an 8-hour energy equivalent level with formula (1):

$$\mathbf{a_{vs} = (1.4a^2_{wx} + 1.4a^2_{wy} + a^2_{wz})^{1/2}} \qquad 3\text{-}1$$

The vibration vector sum (total value) of the weighted root-sum-quads (r.m.q) acceleration (a_{vq}) in m/s^4 was calculated using formula (2):

$$\mathbf{a_{vq} = (1.4a^4_{wx} + 1.4a^4_{wy} + a^4_{wz})^{1/4}} \qquad 3\text{-}2$$

where a_{wx} is the frequency weighted for the x axis (front/back direction), a_{wy} is the frequency weighted for the y axis (left/right direction) and a_{wz} is the frequency weighted for the z axis (vertical direction). The monitoring of WBV were recorded three time taken as five minutes each hence there were three sets of reading available. The three sets of reading acquired as it can be a means to identify if there are any changes in term of the vibration magnitude produced when the first initiation of the engine, slowly increase the speed till it reach constant speed while vehicles driven on the paved road and towards completion of the journey with vehicles slowing down.

The vector sum for first reading identified as a_{vs1} and a_{vq1}, second reading as a_{vs2} and a_{vq2} and third reading as a_{vs3} and a_{vq3}.The mean value of the three reading then calculated to obtain the final value expressed as a_{ws} and a_{wq}.

The formula used to calculate the mean values from the three set of reading to generate the final a_{ws} and a_{wq} respectively as formula (3) below:

$$\mathbf{a_{ws} = a_{vs1} + a_{vs2} + a_{vs3} / 3} \qquad 3\text{-}3$$

And formula (4) below:

$$\mathbf{a_{wq} = a_{vq1} + a_{vq2} + a_{vq3} / 3} \qquad 3\text{-}4$$

Subsequently the WBV acceleration expressed in a_{ws} and a_{wq} were utilized for calculation of the daily and cumulative dosages. The formulas for calculation as shown in Table 3.2.

Table 3.2: Whole Body Vibration Exposures

Description	Formula (Units)
Measure of WBV magnitude	
a_{ws}	r.m.s
a_{wq}	r.m.q
Measure of daily WBV Exposure	
Current r.m.s over 8 hours [A(8)]	$[\ (h/8) \times (a_{ws})^2\ ]^{1/2}$ (ms^{-2})
Current r.m.q over 8 hours [VDV]	$a_{wq} \times (h \times 60 \times 60\ )^{1/4}$ ($ms^{-1.75}$)
Measure of cumulative WBV Exposure	
Dose 1[Total hours of exposure for total year of employment (T)]	(hours/day) x (days/years) x (total years)
Dose 2 (r.m.s at total dose)	$(a_{ws})T$ ($ms^{-2}h$)
Dose 3 (r.m.s a^2t total dose)	$(a_{ws})^2T$ ($m^2s^{-4}h$)
Dose 4 (r.m.s a^4t total dose)	$(a_{ws})^4T$ ($m^4s^{-8}h$)
Dose 5 (r.m.q at total dose)	$(a_{wq})T$ (ms^{-2} h)
Dose 6 (r.m.q a^2t total dose)	$(a_{wq})^2T$ ($m^2s^{-4}h$)
Dose 7 (r.m.q a^4t total dose)	$(a_{wq})^4T$ ($m^4s^{-8}h$)

a, vibration intensity; a_{ws}, weighted acceleration using r.m.s measure; a_{wq}, weighted acceleration using r.m.q measure; r.m.s, root sums of square; r.m.q, root sums of quads; h, total hours of exposure per day; t, time of exposure; T, total hours of exposure for total years of employment

3.10 Study Variables

3.10.1 Independent Variables

a) Whole Body Vibration Exposures Assessment

The exposure data for WBV was evaluated as independent variables. There were eleven variables available to represents WBV exposures for each driver classify under daily and cumulative exposures (see Table 3.2).

b) Socio-demographic, lifestyles and anthropometric measure

The lists of the sociodemographic, lifestyles and anthropometric measures are shown below. All data were obtained using face to face interview according to structured questionnaire which answer taken as what reported by the drivers. The data for weight and height were their past measurement taken six months prior to data collection then the BMI calculated accordingly.

Socio-demographic	Lifestyles and anthropometric measure
• Age	• Smoking habit
• Gender	• Alcohol intake
• Ethnicity	• Physical activity
• Marital status	• Weight (kg)
• Education level	• Height (cm)
• Monthly income	• Body Mass Index (BMI)

For classification of Body Mass Index, we adapted the values from the Malaysian Clinical Practice Guidelines of Obesity (2004). Furthermore, we also referred the classification of BMI according to the WHO classification especially in the analytical part as most of the studies used for reference were outside from the Asian region (see Table 3.3)

Table 3.3: BMI Classification

BMI classification adapted from Malaysian Clinical Practice Guidelines of Obesity (2004)	BMI classification adapted from WHO
<18.5 kg/m^2 (Underweight)	<18.5 kg/m^2 (Underweight)
18.5 – 22.9 kg/m^2 (Normal)	18.5 – 24.99 kg/m^2 (Normal)
23.0 – 27.4 kg/m^2 (Overweight)	25.0 – 29.99 kg/m^2 (Pre-obese)
>27.5 kg/m^2 (Obese)	≥30.0 kg/m^2 (Obese)

c) Health Complaint and Assessment

The information for the past medical and surgical history, previous trauma at the back region and presence of MSD other than LBP were part of the independent variables. All data were obtained as what reported by the drivers during the face to face interview using the structure questionnaire.

d) Occupational Characteristic and Work Environment

The lists of the occupational characteristics and work environment used in this study are shown below. All data were obtained via face to face interview following the structured questionnaire and data documented as what reported by the drivers.

- Length of employment in current post as driver
- Previous job history
- Extra or part time job
- Duration of driving based on hourly calculation per day and per week
- Total travel mileage converted in day and week (average)
- Working schedule per day basis
- Frequency of going outstation (per week and per month)
- Locality of mostly travelled area (urban or rural)
- Type of road surfaces to mostly travelled area (asphalt or gravel)
- Driving long distance (> 4 hours / >200km): rest taken / co-driver available
- Support service available – cabin for drivers etc.
- Type of vehicles they drive (example: automatic or manual gear box), year of manufacturing and seat adjustability
- Material Manual Handling (types of loads: light loads <5kg, medium loads 5-10kg and heavy load >10kg) and frequency of handling loads; never, occasionally (2-3 times/week) and often (everyday)

3.10.2 Dependent Variables

The outcome measure of LBP was evaluated as dependent variables. The body region was divided according to anatomical position as illustrated in Appendix F. A case of LBP was defined as a driver who self-reported their symptoms with **positive** answer on the occurrence of LBP in the past which occurred at 12 months prior to data collection, four weeks prior to data collection and anytime when LBP happen post driving with or without leg pain and lasting one day or longer assessed based on Nordic Musculoskeletal Questionnaire (NMQ). The pain must be located at “low back” region according to anatomical position and not attributed to any recognizable known specific pathology and no serious spinal pathology identified. The NMQ combined with the red flag characteristics used as a screening tools to identify if the pain were of known specific pathology or involvement of any serious spinal pathology.

3.11 Data Management, Data Analysis and Interpretation of Results

The data were analyzed using the SPSS software version 21.0. Data coding and input were performed by the researcher herself. The data entry was conducted right after completion of data collection from all center. To minimize error, data entry was performed twice. Data cleaning and validation was carried out before commencement of data analysis. The analysis of data consists of descriptive and inferential statistics. The flow chart of data management process is described in Figure 3.3.

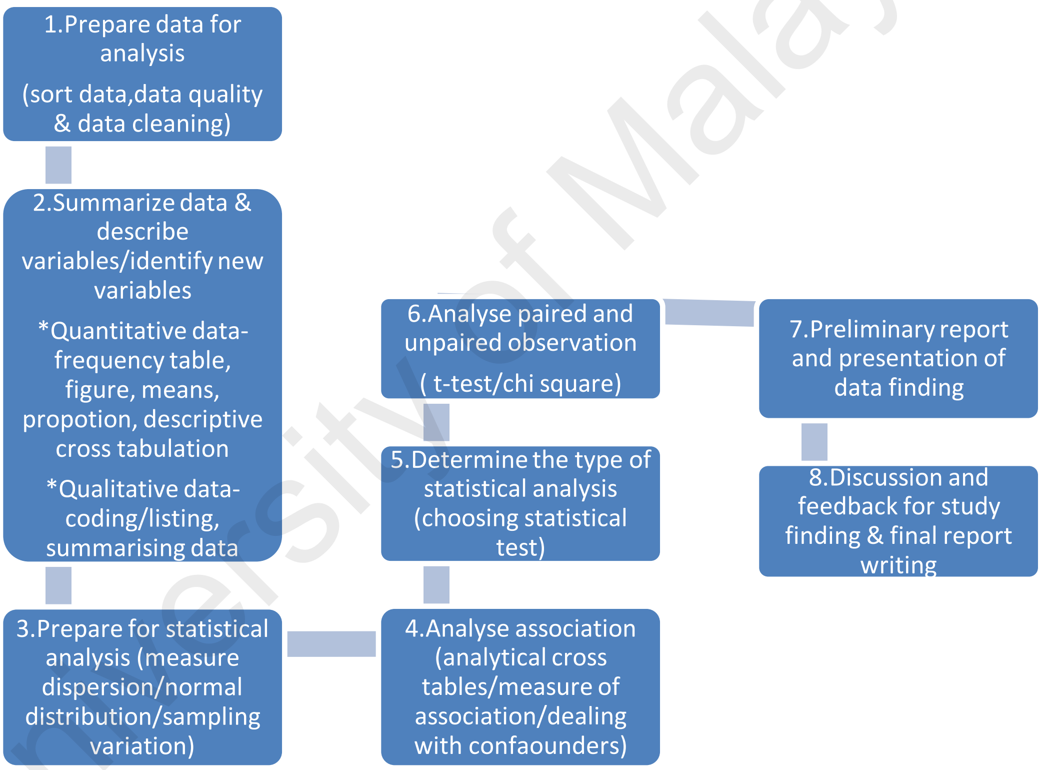


Figure 3.3: Process of data management

In the descriptive statistics, the analysis includes summarization of continuous variables by mean as measure of central tendency and standard deviation (SD) as a measure of dispersion and for categorical variables it was summarize using the frequencies procedures. All continuous variables also checked for data distribution and tested for normality with Kolmogorov-Smirnov. The histogram, box plot and normal Q-Q plot were tabulated to view the data normality. The data obtained for WBV exposures were widely distributed and not symmetrical hence for further analysis data transformed into log form and divided into interquartile range. The division into four quartiles to indicates lowest dose of exposure being in the first quartile (Q1) followed by second quartile (Q2) then third quartile (Q3) and the highest dose being in the fourth quartile (Q4).

In the univariates statistical analysis, continuous variable with presence of two or more means were tested using unpaired student's t test whereas for categorical variables, 2 x 2 contingency table tabulated using percentage given the total (n) and tested using chi-square or fisher's exact. The p value was pre-set at 0.05 to indicate the statistical significant values. The 95% confident interval (CI) was taken as reference for statistical significance. Several identified predictors associated with LBP were assessed by computing the crude odds ratio (OR).

In the multivariate analysis, the regression coefficients and standard errors from multivariate logistics analysis were used to obtain odds ratio (OR) and 95% confident intervals (CI) for low back symptoms with increasing exposure of WBV. Variables were adjusted for several potential confounders, taking low dose at (Q1) as reference. Both exposure variables and cofounding factors were entered in the logistic model as categorical covariates. The statistical tests used in this study is summarized in Table 3.4.

Table 3.4: Summary of Statistical Tests Used

Independent variable	Dependent variable	Statistical Test
<u>Continuous / Categorical</u>	<u>Categorical (dichotomous)</u>	<u>Univariate</u>
Socio-demographic	Symptom of LBP	Independent t-test and chi square, simple logistic regression
Lifestyles	- (12 months prior, 4 weeks prior and Post driving)	
Personal and Health related		
Job History and exposure		<u>Multivariate</u>
Vibration Exposures		Multiple Logistic Regression

3.12 Operational Definition

The operational definition of variables used in this study is summarized in Table 3.5.

Table 3.5: Defining Variables

Conceptual Definition	Operational Definition	Scale of measurement
Age of subject	Age taken at their last birthday	Years
Gender of subject	Gender stated in birth certificate, identification card/passport	_
Ethnicity of subject	Ethnic group stated in subject birth certificate, identification card/passport	_
Marital status of subject	Most current status (past 6 months)	_
Education level of subject	The highest education level achieved by subject	_
Monthly income of subject	The subject personal salary as stated in his/her pay slip including salary from part time job if any or other sources	Ringgit Malaysia
Smoking status	Most current status (past 6 months) as reported by respondents	_
Alcohol intake	Most current status (past 6 month) as reported by respondents	_
Weight of subject	Most current status (past 6 month) as reported by respondents	kg
Height of subject	Most current measurement (past 6 month) as reported by respondents	cm
Length of employment of current status	As counted from the date of his/her appointment latter to date of the interview	months/year
Part time job	Any job which is done outside from his/her normal working routine	_
Low back pain	Case definition pain, aches or discomfort felt localised between the 12th rib and the inferior gluteal folds (with or without leg pain)/lasting 1 day or longer in the previous 4 weeks & 12 months & post driving prior to commencement of data collection	_
Whole Body Vibration	Whole Body Vibration (WBV) is defined as a shaking or jolting of the human body through a supporting surface (usually a seat or the floor) or standing on structure attached to a large, powerful, fixed machine which is impacting or vibrating.	r.m.s and r.m.q
Exercise	Activity requiring physical effort, carried out to sustain or improve health and fitness which adequate excecise define as performing three time per weeks for the duration of 30 minutes per session	-

CHAPTER 4: RESULTS

4.1 Descriptive Analysis

We only managed to recruit 170 drivers with the corresponding response rate of 60.2%. The main reason for not reaching the targeted number was due to limited number of drivers available during the stipulated time of data collection in all data collection centers that participated for this study. The Malaysian Armed Force (Paradise Army Camp based in Kota Belud Sabah) gave commitment to allow participation of 15 drivers. However, they had to be eliminated from analysis because we were not able to perform the WBV monitoring using their Army Truck vehicles. WBV measurement for all types of vehicles is a mandatory requirement of this study. The final number of study participants was 155 drivers who fulfilled the inclusion and exclusion criteria.

The descriptive analysis conducted on for the baseline information include:

1. Socio-demographic characteristics
2. Lifestyles characteristics
3. Personal and health related characteristics
4. Occupational details
5. Whole body vibration exposures assessment

4.1.1 Characteristics of Respondents

4.1.1.1 Socio-demographic Characteristics

All the participants in this study were male drivers with mean age of 39.81 (9.17) years and mean monthly income of RM1856.77 (872.09). Kadazan/Dusun ethnicity contributed to 36.1% and Bajau 25.2%. The rest of the *bumiputra* ethnicity were grouped together with 38.7%. Around seventy four percent of the participants completed their secondary education and 91.6% of them were married (Table 4.1).

Table 4.1: Socio-Demographic Characteristics of the Participants

Variables	n	%	Mean [Min, Max]	± SD
Age (Years)			39.81 [24, 68]	9.17
Monthly Income (RM)			1856.77 [800, 6000]	872.09
Gender				
Male	155	100		
Ethnicity				
Kadazan/Dusun	56	36.1		
Bajau	39	25.2		
Other	60	38.7		
Education				
Primary	27	17.4		
Secondary	115	74.2		
Tertiary	13	8.4		
Marital Status				
Single/Divorced	13	8.4		
Married	142	91.6		

4.1.1.2 Lifestyles Characteristics

More than half of the participants (58.7%) did not routinely perform adequate exercise activities. A person is considered to have adequate exercise if they regularly perform exercise three times per week for the duration of 30 minutes per session. A small percentage of the participants (3.2%) were actively engaged in vigorous physical activity. Vigorous activities is defined as involvement in extreme sports such as rock climbing and motorsports. Almost half (49.6%) of the participants were smokers, and a sizeable percentage (35.5%) were either regular or occasional drinkers (Table 4.2).

Table 4.2: Lifestyles Characteristics of the Participants

Variables	n	%
Exercise		
Adequate	64	41.3
Not Adequate	91	58.7
Rigorous Activity		
Yes	5	3.2
No	150	96.8
Current Smoking Status		
Smoker	76	49.0
Quitter	47	30.3
Non-Smoker	32	20.6
Alcohol Consumption		
Regular	20	12.9
Occasional	35	22.6
Non-alcoholic	100	64.5

4.1.1.3 Personal and Health Related Characteristics

The results for the anthropometry and other health related characteristics are presented in Table 4.3. The means height of the participants was 165.6 (SD=7.7) cm with the mean weight of 73.0 (SD=12.6) kg. The mean BMI was 26.7 (SD=4.6) kg/m^2 which is within the overweight range and if according to classification most drivers fall under the category of normal and pre-obese. The classification of BMI was following the WHO classification however due to small number of participants who is underweight therefore it was regroup under normal category. Majority of the participants did not report on any past medical or surgical history (80.6%). The proportions of drivers having symptoms of LBP at twelve months prior were 58.4%, at four weeks prior were 36.8% and post driving were 24.4%.

Table 4.3: Personal and Health Related Characteristics of the Participants

Variables	n	%	Mean [Min, Max]	± SD
Height (cm)			165.6 [152.0, 188.0]	7.7
Weight (kg)			73.0 [40.0, 112.0]	12.6
BMI (kg/m^2)			26.7 [16.0, 38.0]	4.6
BMI (kg/m^2)				
Normal (≤ 24.99)	60	38.7		
Pre-Obese (25.00 to 29.99)	60	38.7		
Obese (≥ 30.00)	35	22.6		
Past Medical & Surgical History				
Yes	30	19.4		
No	125	80.6		
Musculoskeletal pain other than LBP				
Yes	77	49.7		
No	78	50.3		
Low Back Pain at twelve months				
Yes	85	54.8		
No	70	45.2		
Low Back Pain at four weeks				
Yes	57	36.8		
No	98	63.2		
Low Back Pain at post driving				
Yes	38	24.5		
No	117	75.5		

Thirty of drivers (19.4%) admitted having been diagnosed with disease in the past. The most common diseases reported were hypertension (n=13, 43.3%), combination of hypertension and diabetic (n=6, 20.0%), asthma (n=3, 10.0%), gout (n=3, 10.0%), allergic (n=2, 6.67%), diabetes (n=1, 3.33%), transient ischemic attack (n=1, 3.33%) and hypercholesterolemia (n=1, 3.33%). The data presented in Table 4.4.

Table 4.4: Number of Drivers With Past Medical and Surgical History (n=30)

Types of disease	Number of drivers (%)
Hypertension	13 (43.3)
Hypertension and Diabetic	6 (20.0)
Asthma	3 (10.0)
Gout	3 (10.0)
Allergic	2 (6.67)
Diabetic	1 (3.33)
Transient Ischemic Attack (TIA)	1 (3.33)
Hypercholesterolemia	1 (3.33)
Total	30 (100.0)

Seventy-seven drivers (49.7%) reported to have experienced musculoskeletal pain other than the low back region. The four most common regions reported with musculoskeletal disorders were the shoulder (n=26, 33.7%), knee (n=22, 28.5%), neck (n=13, 16.8%) and upper back (n=7, 9.1%). The results are presented in Table 4.5.

Table 4.5: Musculoskeletal Pain Other Than Low Back Region (n=77)

Region	Number of drivers (%)
Shoulder	26 (33.7)
Knee	22 (28.5)
Neck	13 (16.8)
Upper Back	7 (9.1)
Wrist/Hand	3 (3.8)
Hip/Thigh	3 (3.8)
Ankle/Feet	3 (3.8)
Total	77 (100.0)

4.1.1.4 Occupational Details

a) Vehicles Characteristics

The types of vehicles involved in this study were divided into eight sub classes whereby the most common type of vehicle operated by the drivers was multipurpose vehicles (n=30, 19.4%) and the least common was sport utilities vehicles (n=12, 7.7%). Most of the vehicles involved in this study were equipped with manual gear transmission type (n=126, 81.3%). We also found that about 22 vehicles (14.2%) have been in service for more than ten years. The results of this analysis are summarized in Table 4.6.

Table 4.6: Vehicles Characteristics

Variables	n	%
Types of Vehicles		
Multipurpose Vehicles (MPV)	30	19.0
Bus	27	17.0
Ambulance	20	13.0
Fire Fighter Truck	19	12.3
Lorry/Truck	17	11.0
Garbage Compactor Truck	15	10.0
Saloon Car	15	10.0
Sport Utility Vehicles (SUV)	12	7.7
Age of Vehicles (years)		
≤5	60	38.7
6 - 9	73	47.1
≥10	22	14.2
Gear Transmission		
Manual	126	81.3
Semi/Automatic	29	18.7

b) Work Characteristics

Majority of the drivers in this study worked with the government (n=125, 80.6%). More than half of the drivers worked in shifts (n=91, 58.7%). Only 29 (18.7%) of the participants worked within officer hours. More than half of the drivers needed to performed outstation duty (n=87, 56.1%). A big majority of the drivers reported to have previous jobs (n=146, 94.2%). Among the participants who reported to have previous job, 74 (50.7%) had a job related to driving. About a fifth of the drivers reported to have a part time job (n=34, 21.9%). Among the drivers who reported to have a part time job, 9 (26.4%) were involved in part time job related to driving. The results of this analysis are summarized in Table 4.7.

Table 4.7: Work Characteristics

Variables	n	%
Sector		
Government	125	80.6
Private	30	19.4
Working Schedule		
Office Hours	29	18.7
Shift	91	58.7
Other	35	22.6
Outstation		
Yes	87	56.1
No	68	43.9
Previous Job		
Yes	146	94.2
No	9	5.8
Previous Job (Driving related) n=146		
Yes	74	50.7
No	72	49.3
Part Time Job		
Yes	34	21.9
No	121	78.1
Part Time Job (Driving related) n=34		
Yes	9	26.4
No	25	73.5

c) Work Duration

The mean duration of employment for the current job reported by the drivers in this study was 8.4 (SD=7.5) years. However, the mean for total years of employment as drivers was 12.7 (SD=9.3) years. The total years of employment as drivers includes driving exposure in the past if their previous job were related to driving. The mean working hours per day/shift for the drivers was 10.0 (SD=3.1) hours. However, the mean duration of driving per day/shift was 4.9 (SD=1.8) hours. The mean accumulated hours of driving reported per week was 36.1 (SD=15.2) hours and the mean per month was 152.8 (SD=64.8) hours. The participants in this study worked with mean of 6.1 (SD=1.2) days per week, 25.5 (SD=5.1) days per month and 306.5 (SD=61.6) days per year. The mean mileage accumulated were 123.0 (SD=58.4) km per day, 773.7 (SD=426.3) km per week and 3275.9 (SD=1809.7) km per month. This analysis is summarized in Table 4.8.

Table 4.8: Work Duration

Variables	Mean [Min, Max]	± SD
Duration of employment, current post (years)	8.4 [1.0, 37.0]	7.5
Total Duration of employment as driver (years)	12.7 [1.0, 40.0]	9.3
Duration of working per day/shift (hours)	10.0 [7.0, 24.0]	3.1
Duration of driving per day/shift (hours)	4.9 [2.0, 10.0]	1.8
Duration of driving per week (hours)	36.1 [9.3, 70.0]	15.2
Duration of driving per month (hours)	152.8 [37.3, 300.0]	64.8
Mileage per day/shift (km)	123.0 [33.0, 280.0]	58.4
Mileage per week (km)	773.7 [160.0, 1960.0]	426.34
Mileage per month (km)	3275.9 [640.0, 8400.0]	1809.7
Days of working per week (days)	6.1 [4.0, 7.0]	1.2
Days of working per month (days)	25.5 [16.0, 30.0]	5.1
Days of working per year (days)	306.5 [192.0, 360.0]	61.6

d) Work Habit

While performing their duty as a driver, 92.9% the participants claimed to drive about four hours or less before taking a rest. In terms of rest duration, only 58.1% of the participants took 16 minutes or more rest time before they continued to drive. This analysis is summarized in Table 4.9.

Table 4.9: Work Habit

Variables	n	%
Duration of driving before resting		
≤ 4 hours	144	92.9
>4 hours	11	7.1
Duration of rest taken		
≤ 15 minutes	65	41.9
>15 minutes	90	58.1

e) Other Physical Exposure at Work

A big majority of the drivers were involved in manual material handling (MMH) (n=143, 92.3%). The commonest posture adapted while driving was the torso against backrest (61.3%) but at same time drivers may adapt combination of torso bent, twist and tilt (n=16, 10.3%). This analysis is summarized in Table 4.10.

Table 4.10: Other Physical Exposure at Work

Variables	n	%
Manual Material Handling		
Yes	143	92.3
No	12	7.7
Posture While Driving		
Torso against backrest	95	61.3
Torso Straight	44	28.4
Combination (Torso bent/twist/tilt)	16	10.3

4.1.2 Whole Body Vibration Exposures Assessment

4.1.2.1 Crest Factor

The values of the crest factor were recorded to determine the suitability of the methods being adapted for the calculation of the WBV exposure. The reading being observed showed in general that about half (49.0% in first reading, 54.2% in second reading and 52.3% in third reading) of the crest factors for the z-direction were above nine. Both x- and y- direction had higher proportion of reading that below or equivalent to nine. The proportions of first, second and third reading for x-axis were 78.7%, 76.8% and 79.4% respectively and y-axis recorded proportions of 83.2%, 87.8% and 86.5% for first, second and third reading respectively. This analysis is summarized in Table 4.11. Crest factor above nine indicates that the basic evaluation alone is not sufficient to quantify WBV. Based on the reading generated in this study, there were proportions of crest factor that exceeded nine. Therefore, this study includes both basic and additional evaluations methods for WBV.

Table 4.11: Crest factor

Reading	Acceleration	Crest Factor (n=155)	
		≤ 9 n (%)	> 9 n (%)
First Reading	$\mathbf{a}_{wx1}$	122 (78.7)	33 (21.3)
	$\mathbf{a}_{wx2}$	119 (76.8)	36 (23.2)
	$\mathbf{a}_{wz3}$	123 (79.4)	32 (20.6)
Second Reading	$\mathbf{a}_{wy2}$	129 (83.2)	26 (16.8)
	$\mathbf{a}_{wy2}$	136 (87.8)	19 (12.3)
	$\mathbf{a}_{wy2}$	134 (86.5)	21 (13.5)
Third Reading	$\mathbf{a}_{wz3}$	79 (51.0)	76 (49.0)
	$\mathbf{a}_{wz3}$	71 (45.8)	84 (54.2)
	$\mathbf{a}_{wz3}$	74 (47.7)	81 (52.3)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.s measure in x-axis; a_{wy}, weighted acceleration using r.m.s measure in y-axis a_{wz}, weighted acceleration using r.m.s measure in z-axis

4.1.2.2 Basic and Additional Evaluation

Report on the basic and additional evaluation were expressed in frequency weighted acceleration using the r.m.s and r.m.q respectively. There are three axes described as a_{wx}, a_{wy} and a_{wz} with vector sums (a_{vs} and a_{vq}). Please refer chapter 3.9.

The acceleration magnitude was documented to describe the pattern of vibration produced according to types of vehicles. Three sets of reading presented in Table 4.12 to Table 4.14 for the acceleration expressed in r.m.s and another three sets in Table 4.15 to Table 4.17 for acceleration expressed in r.m.q. From the three axes, z-axis observed as being the most dominant for all types of vehicles. Overall, acceleration magnitude varies by types of vehicles. The data showed that garbage compactor reported the highest reading and ambulance being the lowest on all three sets of reading.

Table 4.12: Acceleration Magnitude of WBV Reported in Mean R.M.S (X, Y and Z-Axis) and Vector Sum According to Typesoof Vehicles (First Reading)

Types of Vehicles	**n (%)**	**r.m.s. (a_{wx1})**		**r.m.s. (a_{wy1})**		**r.m.s. (a_{wz1})**		**Vector Sum (a_{vs1})**	
		Mean ± SD	**(Min, Max)**	**Mean ±SD**	**(Min, Max)**	**Mean ±SD**	**(Min,Max)**	**Mean ±SD**	**(Min, Max)**
Bus	27 (17.0)	0.2265 ± 0.0925	(0.1176, 0.5389)	0.1959 ± 0.0336	(0.1421, 0.2761)	0.3732 ± 0.1046	(0.1556, 0.5476)	0.5683 ± 0.1476	(0.3015, 0.9759)
MPV	30 (19.0)	0.2127 ± 0.0574	(0.1488, 0.4737)	0.1837 ± 0.0425	(0.1275, 0.3027)	0.3419 ± 0.0594	(0.2042, 0.4581)	0.5145 ± 0.1155	(0.1180, 0.8349)
Saloon Car	15 (10.0)	0.2036 ± 0.0603	(0.1119, 0.3311)	0.1401 ± 0.0280	(0.1028, 0.1921)	0.3870 ± 0.0680	(0.2612, 0.5242)	0.5254 ± 0.0799	(0.3498, 0.6771)
Lorry	17 (11.0)	0.2488 ± 0.0701	(0.1408, 0.3681)	0.2508 ± 0.0549	(0.1531, 0.3503)	0.6638 ± 0.2467	(0.2208, 1.1092)	0.8415 ± 0.2278	(0.4558, 1.2019)
Fire Fighter	19 (12.3)	0.2050 ± 0.0797	(0.0742, 0.3750)	0.2047 ± 0.0591	(0.0802, 0.3016)	0.4374 ± 0.1559	(0.1182, 0.7520)	0.6076 ± 0.1719	(0.2245, 0.9149)
SUV	12 (10.0)	0.1825 ± 0.0420	(0.1211, 0.2573)	0.1575 ± 0.0317	(0.1104, 0.2226)	0.3240 ± 0.0721	(0.2101, 0.4887)	0.4719 ± 0.0806	(0.3658, 0.6007)
Ambulance	20 (13.0)	0.1730 ± 0.0511	(0.1057, 0.3184)	0.1625 ± 0.0572	(0.1068, 0.3536)	0.2434 ± 0.0864	(0.1108, 0.4069)	0.4161 ± 0.1237	(0.2515, 0.6656)
Compactor	15 (10.0)	0.3136 ± 0.1061	(0.1791, 0.5018)	0.3159 ± 0.0408	(0.2449, 0.3819)	0.8859 ± 0.1640	(0.6060, 1.1749)	1.0930 ± 0.1709	(0.8538, 1.4516)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.s measure in x-axis; a_{wy}, weighted acceleration using r.m.s measure in y-axis; a_{wz}, weighted acceleration using r.m.s measure in z-axis; r.m.s, root sums of square: $a_{vs,}$ weighted acceleration using r.m.s in vector sum

Table 4.13: Acceleration Magnitude of WBV Reported in Mean R.M.S (X, Y and Z-Axis) and Vector Sum According to Types of Vehicles (Second Reading)

Types of Vehicles	n (%)	r.m.s. (a_{wx2})		r.m.s. (a_{wy2})		r.m.s. (a_{wz2})		Vector Sum (a_{vs2})	
		Mean ± SD	**(Min,Max)**	**Mean ±SD**	**(Min,Max)**	**Mean ±SD**	**(Min, Max)**	**Mean ±SD**	**(Min, Max)**
Bus	27 (17.0)	0.2451 ± 0.0959	(0.1232, 0.4508)	0.1875 ± 0.0352	(0.1256, 0.2673)	0.4341 ± 0.1484	(0.1984, 0.7482)	0.6148 ± 0.1775	(0.3797, 1.0479)
MPV	30 (19.0)	0.2037 ± 0.0782	(0.0726, 0.5327)	0.1675 ± 0.0573	(0.0623, 0.3048)	0.3285 ± 0.1139	(0.0700, 0.7228)	0.4963 ± 0.1428	(0.1852, 0.9447)
Saloon Car	15 (10.0)	0.1947 ± 0.0554	(0.1300, 0.3232)	0.1324 ± 0.0345	(0.0964, 0.2178)	0.3347 ± 0.0646	(0.2584, 0.4797)	0.4753 ± 0.0838	(0.3689, 0.6793)
Lorry	17 (11.0)	0.2671 ± 0.0644	(0.1589, 0.3802)	0.2549 ± 0.0609	(0.1500, 0.3673)	0.7795 ± 0.2535	(0.2884, 1.2575)	0.9536 ± 0.2074	(0.6425, 1.3985)
Fire Fighter	19 (12.3)	0.2540 ± 0.0859	(0.1477, 0.4467)	0.2497 ± 0.0581	(0.1791, 0.3904)	0.5737 ± 0.1454	(0.2597, 0.7898)	0.7545 ± 0.1618	(0.4296, 0.9702)
SUV	12 (10.0)	0.1957 ± 0.0530	(0.1358, 0.3044)	0.1557 ± 0.0131	(0.1392, 0.1799)	0.3709 ±0.0658	(0.2358, 0.4853)	0.5137 ± 0.0789	(0.4063, 0.6563)
Ambulance	20 (13.0)	0.1584 ± 0.0460	(0.0689, 0.2460)	0.1605 ± 0.0546	(0.0441, 0.2512)	0.2539 ± 0.1017	(0.0612, 0.4069)	0.4101 ± 0.1285	(0.1298, 0.6068)
Compactor	15 (10.0)	0.3304 ± 0.1142	(0.1726, 0.5495)	0.2897 ± 0.0539	(0.2283, 0.3850)	0.9935 ± 0.1875	(0.7345, 1.2764)	1.1800 ± 0.1943	(0.8476, 1.4629)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.s measure in x-axis; a_{wy}, weighted acceleration using r.m.s measure in y-axis; a_{wz}, weighted acceleration using r.m.s measure in z-axis; r.m.s, root sums of square: $a_{vs,}$ weighted acceleration using r.m.s in vector sum

Table 4.14: Acceleration Magnitude of WBV Reported in Mean R.M.S (X, Y And Z-Axis) and Vector Sum According to Types of Vehicles (Third Reading)

Types of Vehicles	n (%)	r.m.s. (a_{wx3})		r.m.s. (a_{wy3})		r.m.s. (a_{wz3})		Vector Sum (a_{vs3})	
		Mean ± SD	**(Min,Max)**	**Mean ± SD**	**(Min, Max)**	**Mean ±SD**	**(Min, Max)**	**Mean ± SD**	**(Min,Max)**
Bus	27 (17.0)	0.2325 ± 0.0930	(0.0940, 0.4276)	0.1886 ± 0.0541	(0.0978, 0.3020)	0.4341 ± 0.1390	(0.1483, 0.6607)	0.6144 ± 0.1680	(0.2572, 0.9480)
MPV	30 (19.0)	0.2097 ± 0.0595	(0.1452, 0.4503)	0.1751 ± 0.0425	(0.1151, 0.2780)	0.3354 ± 0.0885	(0.1704, 0.5527)	0.5150 ± 0.1083	(0.3389, 0.7840)
Saloon Car	15 (10.0)	0.2193 ± 0.1500	(0.1211, 0.7161)	0.1611 ± 0.1653	(0.0887, 0.7560)	0.3793 ± 0.1452	(0.2652, 0.8472)	0.4705 ± 0.0828	(0.3466, 0.6771)
Lorry	17 (11.0)	0.2538 ± 0.0696	(0.1567, 0.3811)	0.2308 ± 0.0531	(0.1585, 0.3703)	0.7089 ± 0.1895	(0.4032, 1.1561)	0.8667 ± 0.1787	0.5448, 1.2692)
Fire Fighter	19 (12.3)	0.2427 ± 0.0968	(0.0877, 0.4406)	0.2421 ± 0.0952	(0.0763, 0.4781)	0.4831 ± 0.1431	(0.0926, 0.7295)	0.6918 ± 0.2027	(0.1872, 1.0306)
SUV	12 (7.7)	0.2030 ± 0.0720	(0.1249, 0.3703)	0.1853 ± 0.0687	(0.0767, 0.3597)	0.3676 ± 0.0990	(0.1560, 0.4881)	0.5373 ± 0.1477	(0.2577, 0.8589)
Ambulance	20 (13.0)	0.1649 ± 0.0375	(0.0780, 0.2163)	0.1586 ± 0.0405	(0.0690, 0.2489)	0.2523 ± 0.0896	(0.0931, 0.4088)	0.4127 ±0.0986	(0.1730, 0.5465)
Compactor	15 (10.0)	0.3650 ± 0.2438	(0.1387, 1.1668)	0.2874 ± 0.0669	(0.2046, 0.4667)	0.9924 ± 0.3969	(0.5669, 2.2439)	1.0593 ± 0.2085	(0.6990, 1.3411)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.s measure in x-axis; a_{wy}, weighted acceleration using r.m.s measure in y-axis; a_{wz}, weighted acceleration using r.m.s measure in z-axis; r.m.s, root sums of square: $a_{vs,}$ weighted acceleration using r.m.s in vector sum

Table 4.15. Acceleration Magnitude of WBV Reported in Mean R.M.Q (X, Y and Z-Axis) and Vector Sum according to Types of Vehicles (First Reading)

Types of Vehicles	n (%)	r.m.q. (a_{wx1})		r.m.q. (a_{wy1})		r.m.q. (a_{wz1})		Vector Sum (a_{vq1})	
		Mean ± SD	**(Min,Max)**	**Mean ± SD**	**(Min,Max)**	**Mean ±SD**	**(Min,Max)**	**Mean ± SD**	**(Min,Max)**
Bus	27 (17.0)	1.6203 ± 0.6415	(0.8128, 3.6224)	1.2627 ± 0.3211	(0.1639, 1.8967)	2.8227 ± 0.9145	(1.1535, 4.3702)	3.2801 ± 0.9286	(1.7643, 5.3020)
MPV	30 (19.0)	1.4723 ± 0.3805	(0.9977, 3.0200)	1.2580 ± 0.3073	(0.8166, 2.0773)	2.4412 ± 0.3488	(1.7120, 3.0974)	2.9018 ± 0.4449	(2.1200, 4.4250)
Saloon Car	15 (10.0)	1.2604 ± 0.4475	(0.2492, 2.1979)	0.9669 ± 0.2732	(0.6405, 1.6144)	3.0137 ± 1.4968	(1.9431, 8.1230)	2.9097 ± 0.8660	(0.2005, 3.9530)
Lorry	17 (11.0)	1.7139 ± 0.5005	(0.9038, 2.6212)	1.7278 ± 0.3693	(0.9561, 2.2856)	4.1188 ± 1.5514	(1.8858, 6.6527)	4.6371 ± 1.2688	(2.6642, 6.7092)
Fire Fighter	19 (12.3)	1.4411 ± 0.4724	(0.7031, 2.4575)	1.4768 ±0.3332	(0.7295, 2.1380)	3.1865 ± 0.9737	(1.0715, 5.3827)	3.5237 ± 0.8973	(1.4149, 5.5261)
SUV	12 (7.7)	1.3319 ± 0.3398	(0.7907, 1.8902)	1.0098 ± 0.1737	(0.7447, 1.4028)	2.2908 ± 0.4626	(1.5885, 3.4198)	2.6306 ± 0.4353	(2.1022, 3.5222)
Ambulance	20 (13.0)	1.2754 ± 0.4542	(0.8404, 2.8675)	1.2446 ± 0.6959	(0.8119, 4.0041)	1.9364 ± 0.7317	(0.9616, 4.2413)	2.5076 ± 1.0421	(1.4687, 6.0682)
Compactor	15 (10.0)	2.0663 ± 0.6272	(1.1981, 3.1117)	2.1737 ± 0.2825	(1.6255, 2.6546)	5.7003 ± 0.9092	(4.1448, 7.2360)	5.9735 ± 0.8122	(4.7683, 7.4206)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.q measure in x-axis; a_{wy}, weighted acceleration using r.m.q measure in y-axis; a_{wz}, weighted acceleration using r.m.q measure in z-axis; r.m.q, root sums of quad; $a_{vs,}$ weighted acceleration using r.m.q in vector sum

Table 4.16: Acceleration Magnitude of WBV Reported in Mean R.M.Q (X, Y and Z-Axis) and Vector Sum According to Types of Vehicles (Second Reading)

Types of Vehicles	**n (%)**	**r.m.q. (a_{wx2})**		**r.m.q. (a_{wy2})**		**r.m.q. (a_{wz2})**		**Vector Sum (a_{vq2})**	
		Mean ± SD	**(Min, Max)**	**Mean ± SD**	**(Min,Max)**	**Mean ±SD**	**(Min,Max)**	**Mean ± SD**	**(Min,Max)**
Bus	27 (17.0)	1.8039 ± 0.7652	(0.8710, 3.4634)	1.2232 ± 0.2418	(0.7508, 1.7298)	3.1940 ± 1.2410	(1.2779, 6.4343)	3.6638 ± 1.2079	(2.1069, 6.9072)
MPV	30 (19.0)	1.5021 ± 0.5453	(0.5534, 3.7714)	1.2107 ± 0.4058	(0.6471, 2.2156)	2.3244 ± 0.6382	(0.8453, 3.7454)	2.8496 ± 0.7880	(1.3049, 5.5114)
Saloon Car	15 (10.0)	1.2931 ± 0.3964	(0.8443, 2.2909)	0.8822 ± 0.2535	(0.6607, 1.5241)	2.3492 ± 0.6797	(1.6425, 4.1735)	2.6260 ± 0.6768	(1.8873, 4.5535)
Lorry	17 (11.0)	1.8652 ± 0.4819	(1.1003, 2.4877)	1.7040 ± 0.6009	(1.0023, 3.5481)	5.0923 ± 1.6321	(1.9543, 5.6040)	5.4454 ± 1.3831	(3.5966, 8.4758)
Fire Fighter	19 (12.3)	1.7833 ± 0.6640	(0.9943, 3.4634)	1.5961 ± 0.3899	(1.2023, 2.9007)	4.1883 ± 0.9624	(1.9543, 0.9624)	4.4945 ± 0.9572	(2.3512, 6.0828)
SUV	12 (7.7)	1.3928 ± 0.3476	(0.9772, 2.1528)	1.0446 ± 0.1626	(0.9036, 1.5241)	2.8022 ± 0.5703	(1.6501, 3.5563)	3.0645 ± 0.4900	(2.2964, 3.7637)
Ambulance	20 (13.0)	1.1296 ± 0.3024	(0.6531, 1.7579)	1.0496 ± 0.3880	(0.1505, 1.6032)	1.8620 ± 0.6779	(0.4672, 3.1046)	2.2746 ± 0.6249	(0.9891, 3.5282)
Compactor	15 (10.0)	2.1427 ± 0.7384	(1.1628, 3.6308)	1.7790 ± 0.3104	(1.4158, 2.4660)	6.3413 ± 1.3701	(4.6774, 9.6939)	6.5297 ± 1.3308	(4.7701, 9.7033)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.q measure in x-axis; a_{wy}, weighted acceleration using r.m.q measure in y-axis; a_{wz}, weighted acceleration using r.m.q measure in z-axis; r.m.q, root sums of quad; $a_{vs,}$ weighted acceleration using r.m.q in vector sum

Table 4.17. Acceleration Magnitude of WBV Reported in Mean R.M.Q (X, Y and Z-Axis) and Vector Sum According to Types of Vehicles (Third Reading)

Types of Vehicles	n (%)	r.m.q. (a_{wx3})		r.m.q. (a_{wy3})		r.m.q. (a_{wz3})		Vector Sum (a_{vq3})	
		Mean ± SD	(Min,Max)	Mean ± SD	(Min, Max)	Mean ± SD	(Min, Max)	Mean ± SD	(Min,Max)
Bus	27 (17.0)	1.6359 ± 0.6749	(0.6295, 3.2359)	1.2497 ± 0.3147	(0.8366, 2.0068)	3.3437 ± 1.2295	(1.4240, 7.9433)	3.6984 ± 1.2862	(1.6713, 7.9825)
MPV	30 (19.0)	1.4831 ± 0.4887	(0.9110, 3.3458)	1.1728 ± 0.3043	(0.7194, 1.9187)	2.4569 ± 0.7371	(1.2972, 4.6291)	2.8955 ± 0.7217	(1.8819, 4.9484)
Saloon Car	15 (10.0)	1.1943 ± 0.4496	(0.2917, 2.1979)	0.8154 ± 0.1900	(0.5761, 1.3852)	2.3570 ± 0.5201	(1.7120, 3.5892)	2.6724 ± 0.6081	(1.8136, 3.9530)
Lorry	17 (11.0)	1.7332 ± 0.4579	(0.9539, 2.4294)	1.5249 ± 0.3556	(1.0104, 2.2233)	4.6882 ± 1.1736	(2.9888, 7.3790)	4.8957 ± 1.0901	(3.1930, 7.4220)
Fire Fighter	19 (12.3)	1.7580 ± 0.9710	(0.6761, 4.9602)	1.7761 ± 1.1438	(0.6501, 5.7943)	3.6251 ± 1.2073	(0.7834, 5.4702)	4.1682 ± 1.6997	(1.1687, 9.3219)
SUV	12 (7.7)	1.6232 ± 1.1041	(0.8800, 5.0350)	1.4201 ± 1.0444	(0.6138, 4.6398)	2.7252 ± 0.8719	(1.3900, 4.6345)	3.2967 ± 1.6627	(1.8335, 8.2846)
Ambulance	20 (13.0)	1.2577 ± 0.3596	(0.8680, 2.3174)	1.1712 ± 0.3262	(0.8433, 1.9747)	1.9500 ± 0.8278	(0.6173, 4.5551)	2.4832 ± 0.7355	(1.4646, 4.8381)
Compactor	15 (10.0)	2.0410 ± 0.6975	(0.8630, 2.9854)	1.6909 ± 0.3596	(1.0839, 2.3388)	5.9746 ± 1.4270	(4.1305, 9.0365)	6.1579 ± 1.3706	(4.3858, 9.0437)

a, vibration intensity; a_{wx}, weighted acceleration using r.m.q measure in x-axis; a_{wy}, weighted acceleration using r.m.q measure in y-axis; a_{wz}, weighted acceleration using r.m.q measure in z-axis; r.m.q, root sums of quad; $a_{vs,}$ weighted acceleration using r.m.q in vector sum

4.1.2.3 Daily Exposures

There are four variables for daily WBV exposure, acceleration magnitude expressed as vibration total value or vector sums in a_{ws} and a_{wq} and daily dose as current r.m.s over 8 hours or known as A(8) and daily dose as current r.m.q over 8 hours expressed in VDV. Please refer Chapter 3, Section 3.9 and Table 3.2.

As shown in Table 4.18, the test of normality for all four variables indicated as not normally distributed with p-value reported as less than 0.05.

Table 4.18: Test of Normality for Daily WBV Exposures

WBV Exposures	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
a_{ws}	0.144	155	0.000
a_{wq}	0.141	155	0.000
A(8)	0.183	155	0.000
VDV	0.149	155	0.000

[a].Lilliefors Significance Correction, df. Degree of freedom
a, vibration intensity; a_{ws}, weighted acceleration using r.m.s measure in vector sum; a_{wq}, weighted acceleration using r.m.q measure in vector sum; r.m.s, root sums of square; r.m.q, root sums of quads; A(8), current r.m.s over 8 hours; VDV, current r.m.q over 8 hours

The acceleration magnitude expressed in the vector sums value [a_{ws} and a_{wq}] and daily dose [A(8) and VDV] generated to evaluate the pattern of vibration according to the types of vehicles as shown in Table 4.19.

It was found that different class of vehicles produced different acceleration magnitude. Observation on the vector sum values [a_{ws} and a_{wq}] and daily dose [A(8) and VDV] showed different results for different type of vehicles, which produce the highest acceleration magnitude. Based acceleration expressed in a_{ws} and a_{wq}, the three highest readings were from the Garbage Compactor Trucks followed by Lorries and Fire Fighter Trucks. In term of daily dose expressed in A(8) and VDV, the highest readings came from Garbage Compactor Trucks followed by Lorries and Bus. Thus, it indicates that the higher acceleration magnitude mostly come from the vehicles classified under medium to heavy size, however slight changes noted when time of exposure taken into consideration. Comparatively fire fighter truck was heavier in size in comparison bus thus in principal contributed higher acceleration magnitude but driver who drove this type of vehicles had minimal exposure in term of hours whereas bus usually driven for longer period of time.

Table 4.19: Information of Vibration Exposure According to Types of Vehicle Reported in A_{ws}, A_{wq}, A(8) and VDV

Classification of Vehicles	n (%)	a_{ws}		a_{wq}		A (8)		VDV	
		Mean ± SD	**(Min, Max)**	**Mean ± SD**	**(Min, Max)**	**Mean ±SD**	**(Min, Max)**	**Mean ± SD**	**(Min, Max)**
Bus	27 (17.0)	0.5992 ± 0.1540	(0.35, 0.92)	3.5463 ± 0.9797	(1.97, 5.38)	0.5340 ± 0.1683	(0.27, 0.87)	43.55 ± 13.26	(24.87, 68.20)
MPV	30 (19.0)	0.5086 ± 0.0951	(0.35, 0.85)	2.8823 ± 0.5124	(2.13, 4.92)	0.4448 ± 0.0975	(0.30, 0.69)	35.05 ± 6.364	(25.25, 57.41)
Saloon Car	15 (10.0)	0.4904 ± 0.0578	(0.37, 0.58)	2.7361 ± 0.4972	(1.43, 3.38)	0.4285 ± 0.0542	(0.31, 0.53)	33.29 ± 5.847	(16.78, 39.44)
Lorry	17 (11.0)	0.8873 ± 0.1797	(0.61, 1.27)	4.9928 ± 1.1188	(3.34, 7.35)	0.7582 ± 0.2050	(0.43, 1.20)	60.05 ± 15.30	(42.04, 93.15)
Fire Fighter	19 (12.3)	0.6847 ± 0.0929	(0.52, 0.83)	4.0621 ± 0.6089	(2.95, 5.16)	0.4146 ± 0.0608	(0.28, 0.52)	41.12 ± 5.992	(28.28, 51.17)
SUV	12 (7.7)	0.5077 ± 0.0782	(0.40, 0.66)	2.9973 ± 0.7086	(2.31, 4.98)	0.3629 ± 0.1051	(0.24, 0.58)	32.97 ± 9.819	(23.22, 60.41)
Ambulance	20 (13.0)	0.4130 ± 0.0895	(0.28, 0.56)	2.4219 ± 0.5520	(1.70, 3.77)	0.3739 ± 0.0849	(0.25, 0.57)	30.02 ± 7.049	(21.34, 46.92)
Compactor	15 (10.0)	1.1108 ± 0.1715	(0.91, 1.42)	6.2204 ± 1.0403	(5.01, 3.31)	0.9931 ± 0.1928	(0.68, 1.42)	76.45 ± 13.25	(58.89, 100.79)

a, vibration intensity; a_{ws}, weighted acceleration using r.m.s measure in vector sum; a_{wq}, weighted acceleration using r.m.q measure in vector sum; r.m.s, root sums of square; r.m.q, root sums of quads; A(8), current r.m.s over 8 hours; VDV, current r.m.q over 8 hours

4.1.2.4 Cumulative Exposures

The cumulative exposures for WBV were reported in seven variables described as Dose 1 [total hours of exposure for total duration of employment (T)], Dose 2 [(a_{ws})T], Dose 3[$(a_{ws})^2$T], Dose 4 [$(a_{ws})^4$T], Dose 5 [(a_{wq})T], Dose 6 [$(a_{wq})^2$T] and Dose 7 [$(a_{wq})^4$T]. Please refer Chapter 3.9 and Table 3.2.

The test of normality using the Kolmogorov-Smirnov showed that for all seven variables for cumulative exposures which p-value is less than 0.05 hence, the data are not normally distributed. Please refer Table 4.20.

Table 4.20: Test of Normality for Cumulative WBV Exposures

WBV Exposures	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Dose 1	0.148	155	0.000
Dose 2	0.181	155	0.000
Dose 3	0.260	155	0.000
Dose 4	0.355	155	0.000
Dose 5	0.180	155	0.000
Dose 6	0.255	155	0.000
Dose 7	0.348	155	0.000

[a].Lilliefors Significance Correction, df. Degree of freedom

4.1.2.5 Health Guidance Caution Zone (HGCZ)

The ISO 2631-1:1997 proposed the upper and lower boundaries of the eight-hour Health Guidance Caution Zone (HGCZ). The characterization of the exposures according to the upper and lower boundaries able to differentiate the daily exposures toward WBV into three zones for risks analysis. The standard stated that for exposure below the zone (below lower boundaries expressed in A(8) of 0.45 m/s^2 and VDV of 8.5$m/s^{1.75}$), health effects have not been clearly documented and/or objectively observed; in the zone (reading ranged between 0.45m/s^2 to 0.9m/s^2 expressed in A(8) and 8.5$m/s^{1.75}$ to 17$m/s^{1.75}$ expressed in VDV), caution with respect to potential health risks is indicated and above the zone (exceeded the upper boundaries expressed in A(8) of 0.9 m/s^2 and VDV of 17.0 $m/s^{1.75}$) health risks are likely.

The data obtained for daily measures in A(8) and VDV were compared with the values recommended using this HGCZ. Reported in A(8) using the weighted acceleration in r.m.s the number of reading with minimal risks were 51.0% with 40.0% reported with potential health risk and 9.0% likelihood in occurrence of the health risks. Meanwhile for the value reported in VDV using the weighted acceleration in r.m.q, it was dominated with 99.4% with health risks likely to happen. Based on the readings generated for the daily level of vibration exposure in in VDV (r.m.q), it was found that exposure to vibrations were of high severity as all drivers either within or exceeded the recommendation by HGCZ as opposed to the reading obtained with A(8) (r.m.s), showed that the number of readings about half of the drivers fall below the HGCZ. This analysis is summarized in Table 4.21.

Selection of WBV evaluation methods either using basic evaluation (r.m.s), A(8) alone or with additional evaluation (r.m.q), VDV influenced the level and severity of exposure to vibration.

Table 4.21: Individual WBV exposures expressed in A(8) and VDV with Health Risk Analysis based on HGCZ

WBV Exposure	Health Risk Analysis		
	Minimal/No n (%)	Potential Health Risk n (%)	Health Risk Likely n (%)
A(8)	79 (51.0%)	62 (40.0%)	14 (9.0%)
VDV	0 (0%)	1 (0.6%)	154 (99.4%)

A(8), current r.m.s over 8 hours; VDV, current r.m.q over 8 hours

Based on types of vehicles it was observed that when using the WBV exposures reported in A(8) higher percentage reported with minimal risks especially from MPV, saloon car, fire fighter truck, SUV and ambulance. However, when health risk analysed using the exposures reported in VDV almost all types of vehicles exceeded the health caution zone as proposed by HGCZ (see Table 4.22).

Table 4.22: WBV Exposures According to Types of Vehicles Expressed in A(8) and VDV With Health Risk Analysis Based on HGCZ

Types of Vehicles (n)	Health Risk Analysis					
	Minimal/No n (%)		Potential Health Risk n (%)		Health Risk Likely n (%)	
	A(8)	VDV	A(8)	VDV	A(8)	VDV
Bus (27)	9 (33.3%)	0 (0%)	18 (66.7%)	0 (0%)	0 (0%)	27 (100%)
MPV (30)	19 (63.3%)	0 (0%)	11 (36.7)	0 (0%)	0 (0%)	30 (100%)
Saloon Car (15)	10 (66.7%)	0 (0%)	5 (33.3%)	1 (6.7%)	0 (0%)	14 (93.3%)
Lorry (17)	1 (5.9%)	0 (0%)	13 (76.5%)	0 (0%)	3 (17.6%)	17 (100%)
Fire Fighter Truck (19)	14 (73.7%)	0 (0%)	5 (26.3%)	0 (0%)	0 (0%)	19 (100%)
SUV (12)	9 (75.0%)	0 (0%)	3 (25.0%)	0 (0%)	0 (0%)	12 (100%)
Ambulance (20)	17 (85.0%)	0 (0%)	3 (15.0%)	0 (0%0	0 (0%)	20 (100%)
Compactor (15)	0 (0%)	0 (0%)	4 (26.7%)	0 (0%)	11 (73.3%)	15 (100%)

A(8), current r.m.s over 8 hours; VDV, current r.m.q over 8 hours

4.2 Univariate Analysis

The association between the various covariates and LBP were evaluated according to socio-demographic characteristics, lifestyles characteristics, personal and health related characteristics, occupational details groups and WBV exposures assessment.

4.2.1 Characteristics of Respondents

4.2.1.1 Socio-demographic characteristics

There were five covariates under the group socio-demographic characteristics, namely age, monthly income, ethnicity, educational level and marital status. It was found that drivers who attained tertiary education had a higher proportion of suffering from

LBP. About 69% of drivers who attained tertiary education had LBP past 12 months, 53.8% past four weeks and 46.2% post driving which were higher compared to the other level of education. However, none of these differences were statistically significant at $p<0.05$ level of significance. The association between educational level and LBP past four weeks and post driving exposure to WBV were barely significant. The outcome of this analysis is summarized in Table 4.23.

On further evaluation using regression analysis, it showed association of LBP with increasing OR with increasing level of education. In this analysis, we found that drivers who attained tertiary education were five times at higher odds to have experienced LBP past four weeks prior (OR=5.133; 95%CI= 1.192 - 22.106). Drivers who attained tertiary education had a 12 times higher odd to have symptoms of LBP post driving (OR=12.461; 95%CI=1.667 - 93.149). These findings indicate that drivers who achieved tertiary education had higher risks to experienced LBP in comparison to those attained lower educational level.

Analysis on age, ethnicity, marital status and monthly income did not reveal any significant association with symptoms of LBP at all three points of assessment. Results of this analysis is presented in Table 4.23 and Table 4.24.

Table 4.23: Association Between Socio-Demographic Characteristics with LBP among the Respondents

Socio demographic	LBP @ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	***Yes***		**No**	***Yes***		**No**	***Yes***	
	Mean (SD)	Mean (SD)	Mean diff (95% CI)	Mean (SD)	Mean (SD)	Mean diff (95% CI)	Mean (SD)	Mean (SD)	Mean diff (95% CI)
Age (years)	40.87 (8.89)	38.94 (9.36)	1.93 (-0.986, 4.847)	39.92 (8.79)	39.63 (9.86)	0.287 (-2.740, 3.313)	39.97 (8.92)	39.32 (10.01)	0.659 (-2.732, 4.049)
Monthly Income (RM)	1941.61 (1023.75)	1786.89 (722.83)	154.72 (-123.17, 432.61)	1849.68 (934.65)	1868.95 (760.33)	-19.264 (-307.18, 268.65)	1846.40 (906.26)	1888.68 (767.60)	-42.28 (364.95, 280.39)
	n (%)	n (%)	p	n (%)	n (%)	p	n (%)	n (%)	p
Ethnicity									
Kadazan/Dusun	28 (50.0)	28 (50.0)	0.395	39 (69.6)	17 (30.4)	0.458	45 (80.4)	11 (19.6)	0.544
Bajau	19 (48.7)	20 (51.3)		23 (59.0)	16 (41.0)		29 (74.4)	10 (25.6)	
Others	23 (38.3)	37 (61.7)		36 (60.0)	24 (40.0)		43 (71.7)	17 (28.3)	
Educational Level									
Primary	15 (55.6)	12 (44.4)	0.317	22 (81.5)	5 (18.5)	0.056**	24 (88.9)	3 (11.1)	0.051**
Secondary	51 (44.3)	64 (55.7)		70 (60.9)	45 (39.1)		86 (74.5)	29 (25.2)	
Tertiary	4 (30.8)	9 (69.2)		6 (46.2)	7 (53.8)		7 (53.8)	6 (46.2)	
Marital Status									
Single/Divorced	5 (38.5)	8 (61.5)	0.612	6 (46.2)	7 (53.8)	0.182	9 (69.2)	4 (30.8)	0.584
Married	65 (45.8)	77 (54.2)		92 (64.8)	50 (35.2)		108 (76.1)	34 (23.9)	

**indicate borderline p value (< 0.05) for chi square test

Table 4.24: Association Between Sociodemographic and LBP among the Participants (n=155)

Risks Factors	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ post driving	
	Crude OR	95% CI	Crude OR	95% CI	Crude OR	95% CI
Age (years)						
≤ 30	1.00		1.00		1.00	
31 to 40	0.833	0.322 - 2.158	0.710	0.279 – 1.808	1.373	0.384 – 4.908
41 to 50	0.482	0.172 – 1.352	0.713	0.256 – 1.987	1.389	0.330 – 5.748
≥ 51	0.476	0.151 – 1.496	0.636	0.200 – 2.028	1.883	0.350 – 10.119
Marital Status						
Single/Divorced	1.00		1.00		1.00	
Married	0.740	0.231- 2.374	0.466	0.148 – 1.462	0.931	0.224 – 3.869
Ethnicity						
Kadazan/Dusun	1.00		1.00		1.00	
Bajau	1.053	0.456 – 2.385	1.596	0.678 – 3.754	1.564	0.558 – 4.380
Others	1.609	0.769 – 3.366	1.529	0.709 – 3.300	2.206	0.866 – 5.621
Educational Level						
Primary	1.00		1.00		1.00	
Secondary	1.569	0.675 – 3.646	2.829	0.999 – 8.009	4.011	0.974 – 16.516
Tertiary	2.812	0.693 – 11.419	5.133	1.192 – 22.106*	12.461	1.667 – 93.149*
Income (RM)						
≤ 3000	1.00		1.00		1.00	
≥ 3000	0.520	0.174 – 1.524	0.600	0.181 – 1.970	0.283	0.054 – 1.477

***indicate statistically significant results

4.2.1.2 Lifestyles Characteristics

Under lifestyles characteristics, there were four covariates, namely exercise, rigorous activity, current smoking status and frequency of alcohol consumption. Table 4.25 and Table 4.26 summarizes the analysis of these covariates.

Generally, it was found that LBP had a significant association with smoking habit and alcohol consumption. There was no significant association found for exercise and rigorous activity with LBP.

In this study, 28.9% of drivers who were smoker had post driving LBP which is higher than drivers who quit smoking (27.7%) or non-smoker (9.4%). However, this association was not statistically significant (p=0.081). It was also found that 60% of drivers who were non-alcoholic had LBP past 12 months into their job as driver. This proportion is significantly higher (p=0.012) compared to drivers who drank occasionally (34.2%) and drivers who drank regularly (50.0%).

Further assessment using logistic regression showed that drivers who smoke had a 3.9 times higher odd of experiencing LBP post driving (OR=3.9; 95%CI=1.086 – 14.277). Drivers who drank regularly had thrice lesser odds of to have symptoms of LBP past 12 months (OR=0.306; 95%CI=0.137 – 0.687).

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Table 4.25: Association Between Lifestyles and Behavior Characteristics With LBP among Respondents

Lifestyles Behaviour	LBP @ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	***Yes***		**No**	***Yes***		**No**	***Yes***	
	n (%)	n (%)	p	n (%)	n (%)	p	n (%)	n (%)	p
Exercise									
Not Adequate (≤ 2x/weeks)	39 (42.9)	52 (57.1)	0.492	55 (60.4)	36 (39.6)	0.391	66 (72.5)	25 (27.5)	0.308
Adequate (≥ 3x/weeks)	31 (48.4)	33 (51.6)		43 (67.2)	21 (32.8)		51 (79.7)	13 (20.3)	
Rigorous Activity									
No	67 (44.7)	83 (55.3)	0.498	94 (62.7)	56 (37.3)	0.429	113 (75.3)	37 (24.7)	0.811
Yes	3 (60.0)	2 (40.0)		4 (80.0)	1 (20.0)		4 (80.0)	1(20.0)	
Current Smoking Status									
Smoker	35 (46.1)	41 (53.9)	0.973	46 (60.5)	30 (39.5)	0.717	54 (71.1)	22 (28.9)	0.081
Quitter	21 (44.7)	26 (55.3)		30 (63.8)	17 (36.2)		34 (72.3)	13 (27.7)	
Non-Smoker	14 (43.8)	18 (56.3)		22 (68.8)	10 (31.3)		29 (90.6)	3 (9.4)	
Frequency of alcohol consumption									
Non-alcoholic	37 (37.0)	63 (63.0)	0.012*	59 (59.0)	4 (41.0)	0.337	74 (74.0)	26 (26.0)	0.822
Occasional	23 (65.7)	12 (34.3)		25 (71.4)	10 (28.6)		27 (77.1)	8 (22.9)	
Regular	10 (50.0)	10 (50.0)		14 (70.0)	6 (30.0)		16 (80.0)	4 (20.0)	

*****indicate statistical significant result, $p < 0.05$

Table 4.26: Association Between Lifestyles Characteristics and LBP among the Participants (n=155)

Risks Factors	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ Post driving	
	Crude OR	95% CI	Crude OR	95% CI	Crude OR	95% CI
Exercise						
0 (Days/Week)	1.00		1.00		1.00	
≤ 2 (Days/Week)	0.319	0.080 – 1.272	0.570	0.170 – 1.908	0.480	0.114 – 1.456
≥ 3 (Days/Week)	0.350	0.089 – 1.370	0.729	0.224 – 2.378	0.552	0.162 – 1.883
Current Smoking Status						
Non-Smoker	1.00		1.00		1.00	
Quitter	0.963	0.390 – 2.380	1.247	0.480 – 3.241	3.696	0.959 – 14.252
Smoker	0.911	0.397 – 2.092	1.435	0.597 – 3.451	3.938	1.086 – 14.277*
Alcohol Intake						
Non-alcoholic	1.00		1.00		1.00	
Occasionally	0.587	0.224 – 1.543	0.361	0.219 – 1.173	0.712	0.218 – 2.323
Regularly	0.306	0.137 – 0.687*	0.195	0.250 – 1.326	0.843	0.341 – 2.088

*indicate statistically significant results

4.2.1.3 Personal and Health Related Characteristics

Under personal and health related characteristics heading, there were five covariates. However, weight and height were analyzed as BMI in regression analysis Table 4.27 and Table 4.28 summarizes the analysis of these covariates. In this analysis, significant association was found between LBP and history of MSD other than LBP but none with BMI or past medical history (PMH).

At assessment of LBP past 12 months, 63.3% of drivers who had MSD other than LPB developed LBP. This proportion is significantly higher (p=0.029) than the 46.2% of drivers who did not have MSD other than LBP. At assessment of LBP past four weeks, 48.1% of drivers who had MSD other than LPB developed LBP. This proportion is significantly higher (p=0.004) than the 25.6% of drivers who did not have MSD other than LBP. The proportion of drivers who had MSD other than LBP and had Post Driving LBP was 33.8%. Again, this proportion is significantly higher (p=0.008) compared to the 15.4% of drivers who had no MSD other than LBP.

In logistic regression analysis, it was found that drivers who had MSD other than LBP were two times at higher odds (OR=2.042; 95%CI=1.073-3.885) to have symptoms of LBP past 12 months. At assessment of LBP past four weeks, drivers who had MSD other than LBP had about 2.7 times higher odds (OR=2.682:95%CI=1.363-5.270) of experiencing LBP. Drivers with MSD other than LBP had 2.8 times higher odds (OR=2.804; 95%CI=1.291-6.089) of having LBP post driving.

Table 4.27: Association Between Personal and Health Related Characteristics with LBP among Respondents

Personal & Health Related	LBP @ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	***Yes***		**No**	***Yes***		**No**	***Yes***	
	Mean (SD)	Mean (SD)	Mean diff (95% CI)	Mean (SD)	Mean (SD)	Mean diff (95% CI)	Mean (SD)	Mean (SD)	Mean diff (95% CI)
Weight	72.50 (12.93)	73.47 (12.40)	-0.97 (-5.00,3.06)	72.64 (13.89)	73.70 (10.13)	-1.06 (-5.22,3.10)	72.89 (13.58)	73.47 (9.14)	-0.59 (-5.25,4.08)
Height	165.90 (8.47)	165.36 (7.09)	0.53 (-1.93,3.00)	165.36 (7.95)	166.04 (7.35)	-0.68 (-3.23,1.87)	165.31 (7.68)	166.53 (7.87)	-1.22 (-4.09,1.63)
	n (%)	n (%)	p	n (%)	n (%)	p	n (%)	n (%)	p
BMI									
Normal (≤ 24.99)	28 (46.7)	32 (53.3)	0.547	41 (68.3)	19 (31.7)	0.524	48 (80.0)	12 (20.0)	0.571
Pre-obese (25 to 29.99)	29 (48.3)	31 (51.7)		37 (61.7)	23 (38.3)		44 (73.3)	16 (26.7)	
Obese (≥ 30.00)	13 (37.1)	22 (62.9)		20 (57.1)	15 (42.9)		25 (71.4)	10 (28.6)	
PMH									
No	59 46.8	67 (53.2)	0.386	84 (66.7)	42 (33.3)	0.064	97 (77.0)	29 (23.0)	0.365
Yes	11 37.9	18 (62.1)		14 (48.3)	15 (51.7)		20 (69.0)	9 (31.0)	
MSD other than LBP									
No	42 (53.8)	36 (46.2)	0.029*	58 (74.4)	20 (25.6)	0.004*	66 (84.6)	12 (15.4)	0.008*
Yes	28 (36.4)	49 (63.3)		40 (51.9)	37 (48.1)		51 (66.2)	26 (33.8)	

*indicate statistically significant results

Table 4.28: Association Between Personal and Health Related Characteristics and LBP among the Participants (n=155)

Risks Factors	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ post driving	
	Crude OR	95% CI	Crude OR	95% CI	Crude OR	95% CI
BMI						
Normal (≤ 24.99)	1.00		1.00		1.00	
Pre-Obese (25 to 29.99)	0.935	0.457 – 1.915	1.341	0.632 – 2.848	1.455	0.620 – 3.413
Obese (≥ 30.00)	1.481	0.631 – 3.474	1.683	0.683 – 3.834	1.610	0.607 – 4.214
PMH						
No	1.00		1.00		1.00	
Yes	1.441	0.630 – 3.279	2.143	0.947 – 4.851	1.505	0.619 – 3.663
MSD Other Region						
No	1.00		1.00		1.00	
Yes	2.042	1.073 – 3.885*	2.682	1.363 – 5.278*	2.804	1.291 – 6.089*

*indicate statistically significant results

4.2.1.4 Occupational Details Characteristics

Under occupational details characteristics heading, there were four subheadings, namely vehicle characteristics, work characteristics, work duration and work habit and other physical exposure. The results of the univariate analysis are summarized in **Table 4.29 -Table 4.32**. Computation of odds ratio using logistic regression is presented in **Table 4.33**.

i. Under vehicle characteristics, we studied three covariates, namely types of vehicles, age of vehicles in years and types of gear transmission used in the vehicles. These covariates were analyzed for association with LBP at three levels of assessment, i.e. past 12 months, past four weeks and post driving. In summary, there was no significant association between the various covariates with LBP.

ii. Under work characteristics, we studied four covariates, namely “sector”, “work schedule”, “previous job” and “part time job”. In this analysis, we found that LBP was significantly associated with work schedule and part time job of the drivers. At assessment of LBP past four weeks, the proportion of drivers with LBP was significantly higher (p=0.016) among drivers who worked on office hours (51.7%) compared to drivers who worked on shift duty (27.5%) and other work schedule (48.6%). Post driving, the proportion of drivers with LBP was significantly higher (p=0.048) among office hour drivers (37.6%) compared to shift duty drivers (17.6%) or other schedule drivers (31.4%).

    At assessment of LBP past 12 months, the proportion of drivers who had LBP was significantly higher (p=0.013) among those who had a part time job (73.5%) compared to those who did not have one (49.6%). At assessment of LBP past four weeks, the proportion of drivers who had LBP was significantly higher (p=0.027) among those who had a part time job (52.9%) compared to those did not have one (32.2%).

iii. Under work duration, six covariates were included for analysis, namely “employment current position” in year, “total employment” in year, “driving per week” in hour, “distance per day” in kilometer, “distance per year” in kilometer and “days of working” on annual basis. The covariates were analyzed for association with LBP at all three points of assessment, i.e. past 12 months, past 4 weeks and post driving. In summary, there was no significant association between the various covariates in this subheading and symptoms of LBP.

iv. Under work habit and other physical exposure subheading four covariates were included for analysis, namely “driving before resting”, “duration of rest taken”, MMH, and “frequently adapted posture”. In this analysis, we found that LBP was significantly associated with the driver’s frequently adapted posture. At assessment of LBP past four weeks, the proportion of drivers was significantly higher (p=0.045) among those who frequently adopted “torso against backrest” posture (44.2%) compared to those who frequently adopted “torso straight posture” (22.7%) or combination of the two postures (31.3%).

v. In univariate logistic regression analysis, it was found that at assessment of LBP past 4 weeks, drivers who were on shift duty had a 2.8 time lower odd (OR=0.35; 95%CI=0.149-0.837) of experiencing LBP compared to drivers working office hours. Drivers who adopted other work schedule had no significant difference in odds to have symptoms of LBP compared with office hours drivers (OR=0.881;95%CI=0.329-2.360). Post driving, drivers who were on shift duty had a 2.8 time lower odd to have LBP compared to drivers who were on office hours duty (OR=0.349; 95%CI=0.139-0.880). Drivers who adopted other work schedule had no significant difference in odds of experiencing LBP compared to office hours drivers (OR=0.75; 95%CI=0.266-2.112). At assessment of LBP past 12 months, drivers who had a part time job were 2.8 times at higher odds of experiencing LBP (OR=2.824;

95%CI=1.218-6.549). Almost the same findings were elicited at assessment of LBP past four weeks, whereby drivers who had a part time job had a 2.36 times higher odd of experiencing LBP (OR=2.365; 95%CI=1.091-5.120). Logistic regression analysis on the different postures adopted by the drivers when they drove with torso straight had lower odds for assessment of LBP past four weeks (OR=0.371; 95%CI=0.165-0.837) in comparison to other types of posture while driving i.e. torso against backrest and combined posture.

Table 4.29: Association Between Occupational Details (Vehicles Characteristics) with LBP among Respondents

Variables	LBP@ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	**Yes**		**No**	**Yes**		**No**	**Yes**	
	n (%)	n (%)	p	n (%)	n (%)	p	n (%)	n (%)	p
Types of Vehicles									
Type A(Light)	22 (38.6)	35 (61.4)	0.219	31 (54.4)	26 (45.6)	0.206	39 (68.4)	18 (31.6)	0.291
Type B(Medium)	26 (55.3)	21 (44.7)		33 (70.2)	14 (29.8)		37 (78.7)	10 (21.3)	
Type C(Heavy)	22 (43.1)	29 (56.9)		34 (66.7)	17 (33.3)		41 (80.4)	10 (19.6)	
Duration of Vehicles (years)									
≤ 5	30 (50.0)	30 (50.0)	0.341	36 (60.0)	24 (40.0)	0.396	44 (73.3)	16 (26.7)	0.776
6 – 10	33 (45.2)	40 (54.8)		50 (68.5)	23 (31.5)		57 (78.1)	16 (21.9)	
≥ 11	7 (31.8)	15 (68.2)		12 (54.5)	10 (45.5)		16 (72.7)	6 (27.3)	
Gear Transmission									
Manual	58 (46.0)	68 (54.0)	0.650	80 (63.5)	46 (36.5)	0.886	94 (74.6)	32 (25.4)	0.595
Auto/Semi	12 (41.4)	17 (58.6)		18 (62.1)	11 (37.9)		23 (79.3)	6 (20.7)	

*****indicate statistical significant result, $p < 0.05$

Table 4.30: Association Between Occupational Details (Work Characteristics) with LBP among Respondents

Variables	LBP@ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	**Yes**		**No**	**Yes**		**No**	**Yes**	
	n (%)	n (%)	p	n (%)	n (%)	p	n (%)	n (%)	p
Sector									
Government	57 (45.6)	68 (54.4)	0.823	81 (64.8)	44 (35.2)	0.407	95 (76.0)	30 (24.0)	0.760
Private	13 (43.3)	17 (56.7)		17 (56.7)	13 (43.3)		22 (73.3)	8 (26.7)	
Working schedule									
Office hours	11 (37.9)	18 (62.1)	0.435	14 (48.3)	15 (51.7)	0.016*	18 (62.1)	11 (37.6)	0.048*
Shift	45 (44.5)	46 (50.5)		66 (72.5)	25 (27.5)		75 (82.4)	16 (17.6)	
Other	14 (40.0)	21 (60.0)		18 (51.4)	17 (48.6)		24 (68.6)	11 (31.4)	
Previous Job									
No	5 (55.6)	4 (44.4)	0.519	5 (55.6)	4 (44.4)	0.623	6 (66.7)	3 (33.3)	0.526
Yes	65 (44.5)	81 (55.5)		93 (63.7)	53 (36.3)		111 (76.0)	35 (24.0)	
Part Time Job									
No	61 (50.4)	60 (49.6)	0.013*	82 (67.8)	39 (32.2)	0.027*	92 (76.0)	29 (24.0)	0.764
Yes	9 (26.5)	25 (73.5)		16 (47.1)	18 (52.9)		25 (73.5)	9 (26.5)	

*****indicate statistical significant result p < 0.05

Table 4.31: Association Between Occupational Details (Work Duration) with LBP among Respondents

Variables	LBP@ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	**Yes**		**No**	**Yes**		**No**	**Yes**	
	Mean (SD)	Mean (SD)	Mean Diff (95% CI)	Mean (SD)	Mean (SD)	Mean Diff (95% CI)	Mean (SD)	Mean (SD)	Mean Diff (95% CI)
Employment current position (years)	9.71 (7.96)	7.38 (6.87)	2.34 (-0.02,4.69)	9.22 (8.09)	7.07 (6.05)	2.15 (-0.28,4.59)	8.96 (7.88)	6.82 (5.74)	1.39 (-0.59,4.88)
Total employment (years)	13.43 (9.87)	12.15 (8.81)	1.28 (-1.69,4.24)	13.38 (9.47)	11.61 (8.96)	1.76 (-1.29,4.82)	13.32 (9.37)	10.92 (8.97)	1.73 (-1.03,5.82)
Driving per day/shift (hours)	5.77 (1.73)	5.68 (1.89)	0.08 (-0.49,0.67)	5.84 (1.84)	5.53 (1.77)	0.31 (-0.29,0.91)	5.73 (1.83)	5.71 (1.81)	0.02 (-0.65,0.69)
Driving per week (hours)	37.37 (14.96)	34.99 (15.47)	2.37 (-2.49,7.23)	37.39 (15.38)	33.78 (14.85)	3.62 (-1.38,8.61)	36.26 (15.44)	35.48 (14.78)	0.78 (-4.86,6.42)
Mileage per day (km)	120.77 (56.13)	124.91 (60.54)	-4.13 (-22.81,14.55)	120.09 (58.27)	128.11 (58.91)	-8.01 (-7.27,11.23)	119.88 (58.26)	132.76 (58.69)	-12.88 (-34.41,8.64)
Mileage per month (km)	3271.91 (1764.53)	3279.29 (1856.63)	-7.38 (-86.33, 571.57)	3233.61 (1818.08)	3348.77 (1809.17)	-115.16 (-12.39,482.08)	3190.58 (1818.17)	3538.84 (1781.66)	-348.26 (-1015.71,319.18)
Days of working (days per year)	313.0 (62.96)	301.13 (60.58)	11.89 (-7.73,31.53)	309.92 (61.96)	300.63 (61.25)	9.29 (-11.02,29.59)	305.44 (64.03)	309.79 (54.37)	-4.35 (-27.16,18.46)

*****indicate statistical significant result $p < 0.05$

Table 4.32: Association Between Occupational Details (Work Habit & Other Physical Exposure) with LBP Among Respondents

Variables	LBP@ past 12 months			LBP @ past 4 weeks			LBP @ post driving		
	No	**Yes**		**No**	**Yes**		**No**	**Yes**	
	n (%)	n (%)	*p*	n (%)	n (%)	*p*	n (%)	n (%)	*p*
Driving before resting									
≤ 4 hours	64 (44.4)	80 (55.6)	0.516	89 (61.8)	55 (38.2)	0.185	107 (74.3)	37 (25.7)	0.217
> 4 hours	6 (54.5)	5 (45.5)		9 (81.8)	2 (18.2)		10 (90.9)	1 (9.1)	
Duration of rest taken									
≤ 15 minutes	25 (38.5)	40 (61.5)	0.154	38 (58.5)	27 (41.5)	0.296	46 (70.8)	19 (29.2)	0.246
> 15 minutes	45 (50.0)	45 (50.0)		60 (66.7)	30 (33.3)		71 (78.9)	19 (21.1)	
MMH									
No	4 (33.3)	8 (66.7)	0.391	8 (66.7)	4 (33.3)	0.797	9 (75.0)	3 (25.0)	0.968
Yes	66 (46.2)	77 (53.8)		90 (62.9)	53 (37.1)		108 (75.5)	35 (24.5)	
Frequently adapted posture									
Torso against backrest	39 (41.1)	56 (58.9)	0.395	53 (55.8)	42 (44.2)	0.045*	67 (70.5)	28 (29.5)	0.191
Torso straight	22 (50.0)	22 (50.0)		34 (77.3)	10 (22.7)		37 (84.1)	7 (15.9)	
Combined	9 (56.3)	7 (43.8)		11 (68.8)	5 (31.3)		13 (81.3)	3 (18.8)	

*****indicate statistical significant result p < 0.05

Table 4.33: Association Between Selected Factors (Occupational Related) and LBP Among the Respondents (n=155)

Risks Factors	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ post driving	
	Crude OR	95% CI	Crude OR	95% CI	Crude OR	95% CI
Types of Vehicles						
Type A (Light)	1.00		1.00		1.00	
Type B (Medium)	0.508	0.232 – 1.112	0.506	0.224 -1.142	0.586	0.239 -1.432
Type C (Heavy)	0.829	0.384 – 1.788	0.596	0.273 -1.302	0.528	0.217 -1.285
Duration of Vehicles						
≤ 5 years	1.00		1.00		1.00	
6 -10 years	1.212	0.611 – 2.403	0.690	0.338 -1.410	0.772	0.348 – 1.712
≥ 11 years	2.143	0.765 – 6.003	1.250	0.467 – 3.349	1.031	0.344 – 3.095
Work schedule						
Office hours	1.00		1.00		1.00	
Shift	0.625	0.266 – 1.469	0.354	0.149 – 0.837*	0.349	0.139 – 0.880*
Other	0.917	0.334 – 2.517	0.881	0.329 – 2.360	0.750	0.266 -2.112
Outstation						
No	1.00		1.00		1.00	
Yes	0.982	0.490 – 1.756	1.255	0.648 – 2.433	0.829	0.398 – 1.729
Previous Job						
No	1.00		1.00		1.00	
Yes	1.558	0.402 – 6.037	0.712	0.183 – 2.763	0.631	0.150 – 2.654
Part Time Job						
No	1.00		1.00		1.00	
Yes	2.824	1.218 – 6.549*	2.365	1.091 – 5.120*	0.446	0.479 – 2.723
Total years of employment						
≤ 10	1.00		1.00		1.00	
11 – 20	1.626	0.759 – 3.481	0.715	0.333 – 1.535	0.689	0.298 – 1.636
≥ 21	0.561	0.239 – 1.313	0.503	0.200 – 1.263	0.365	0.115 – 1.161

*indicate statistically significant results

Table 4.33: continued

Risks Factors	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ post driving	
	Crude OR	95% CI	Crude OR	95% CI	Crude OR	95% CI
Driving (hours)						
≤ 4	1.00		1.00		1.00	
> 4	0.667	0.195 – 2.284	0.36	0.075 – 1.726	0.289	0.036 – 2.337
Rest (minutes)						
≤ 15	1.00		1.00		1.00	
> 15	0.625	0.327 – 1.195	0.704	0.346 – 1.361	0.648	0.310 – 1.353
MMH						
No	1.00		1.00		1.00	
Yes	0.583	0.168 – 2.025	1.178	0.338 – 4.100	0.972	0.249 – 3.792
MMH (< 5 kg)						
Never	1.00		1.00		1.00	
Occasionally	0.654	0.177 – 2.410	1.077	0.290 – 4.000	1.186	0.286 – 4.918
Often	0.538	0.150 – 1.924	1.255	0.349 – 4.509	0.831	0.203 – 3.393
MMH (5-10 kg)						
Never	1.00		1.00		1.00	
Occasionally	0.574	0.174 – 1.889	0.675	0.209 – 2.182	0.636	0.186 – 2.178
Often	0.574	0.182 – 1.843	1.01	0.329 – 3.106	0.630	0.184 – 1.982
MMH (> 10 kg)						
Never	1.00		1.00		1.00	
Occasionally	1.103	0.475 – 2.565	1.533	0.610 – 3.855	1.486	0.548 – 4.029
Often	1.280	0.544 - 3.013	1.961	0.778 – 4.939	1.050	0.372 – 2.961
Posture						
Torso again backrest	1.00		1.00		1.00	
Torso Straight	0.696	0.339 – 1.429	0.371	0.165 – 0.837*	0.453	0.180 – 1.136
Combined	0.542	0.186 – 1.578	0.574	0.185 – 1.779	0.552	0.146 – 2.089

*indicate statistically significant results

4.2.2 Whole Body Vibration Exposures Assessment

The eleven parameter of vibration exposures in log form were divided into four quartiles. The cut off value for the quartiles in logarithmic values presented in Table 4.34.

Table 4.34: Vibrational Dosages Reported in Logarithmic Values (Cut Off Values)

Quartiles	Vibrational Dosages reported in logarithmic values (cut off values)		
	$\ln(a_{ws})$	**$\ln(a_{wq})$**	
Q1	-0.26 to -0.76	0.35 to 0.97	
Q2	-0.77 to -0.58	0.98 to 1.17	
Q3	-0.59 to -0.28	1.18 to 1.48	
Q4	-0.29 to 0.34	1.49 to 2.11	
	lnA8	**lnVDV**	
Q1	-1.43 to -0.96	3.17 to 4.41	
Q2	-0.97 to -0.81	4.42 to 4.79	
Q3	-0.82 to -0.49	4.80 to 5.42	
Q4	-0.50 to 0.35	5.43 to 6.73	
	lnT		
Q1	5.95 to 8.77		
Q2	8.78 to9.75		
Q3	9.76 to 10.32		
Q4	10.33 to 11.81		
	$\ln(a_{ws})T$	**$\ln(a_{ws})^2T$**	**$\ln(a_{ws})^4T$**
Q1	5.04 to 8.03	4.13 to 7.36	2.30 to 6.12
Q2	8.04 to 9.10	7.37 to 8.54	6.13 to 7.20
Q3	9.11 to 9.83	8.55 to 9.39	7.21 to 8.56
Q4	9.84 to 11.26	9.40 to 11.55	8.57 to 12.14
	$\ln(a_{wq})T$	**$\ln(a_{wq})^2T$**	**$\ln(a_{wq})^4T$**
Q1	6.79 to 9.85	7.63 to 10.88	9.30 to 12.97
Q2	9.86 to 10.87	10.89 to 12.03	12.98 to 14.22
Q3	10.88 to 11.55	12.04 to 12.85	14.23 to 15.68
Q4	11.56 to 12.94	12.86 to 14.92	15.67 to 18.87

In univariate regression analysis, the symptoms of LBP were regressed against eleven parameter of vibration exposures in log form which four classify under daily exposures expressed in a_{ws}, a_{wq}, A(8) and VDV and seven classify under cumulative exposures i.e. Dose 1 [total hours of exposure for total duration of employment (T)], Dose 2 [$(a_{ws})T$], Dose 3[$(a_{ws})^2T$], Dose 4 [$(a_{ws})^4T$], Dose 5 [$(a_{wq})T$], Dose 6 [$(a_{wq})^2T$] and Dose

7 [$(a_{wq})^4T$]. The results as shown in Table 4.35 for daily exposures and Table 4.36 for cumulative exposures.

4.2.2.1 Daily Exposures

In the daily exposures, one statistical significant results demonstrated the indication of dose response as exposure expressed in log form of a_{wq} for drivers in Q2 (OR = 2.602; 95% CI 1.039 to 6.514) for symptoms of LBP past four weeks. The finding indicate that drivers received WBV exposure expressed in log form of a_{wq} at Q2 were 2.602 times likely to experienced LBP in comparison to those received lower dose at Q1. The full results as shown in Table 4.35.

4.2.2.2 Cumulative Exposures

a) Low Back Pain past twelve months

Using the cumulative measures, the odds for experiencing LBP (in comparison with the reference group) of Dose 3 and Dose 6 [$\ln(a_{ws})^2T$ and $\ln(a_{wq})^2T$] for drivers in Q2 (OR = 2.700; 95% C1 1.036 to 7.037) and (OR = 3.053; 95% CI 1.175 to 7.928) respectively. The finding indicate that drivers received WBV exposure in Dose 3 and Dose 6 at Q2 were 2.700 and 3.053 times likely to have symptoms of LBP in comparison to those received lower dose at Q1. The rest of the cumulative measures found to have no significant results at this point of LBP assessment. The results as presented in Table 4.36

b) Low Back Pain past four weeks

The statistical significant results for symptoms of LBP were observed at Q2 with odds (OR= 3.571; 95% CI 1.401 to 9.083), (OR= 3.571; 95% CI 1.404 to 9.083) and (OR= 4.500; 95% CI 1.737 to 11.655) for cumulative measures for exposure in Dose 2 [$\ln(a_{ws})T$], Dose 3 and Dose 6 [$\ln(a_{wq})^2T$] respectively. The finding indicates that the drivers with cumulative exposure in Dose 2, Dose 3 and Dose 6 at Q2 were 3.571 to 4.500

times likely to experienced LBP in comparison to those at Q1. The rest of the cumulative measures found to have no significant finding. The results as presented in Table 4.36.

c) Low Back Pain at Post Driving

In the cumulative measures two statistical significant result observed at Q2 for WBV exposure in Dose 2 [ln(a_{ws})T] and Dose 6 [ln(a_{wsq})^{2}T] with (OR = 3.681; 95% CI 1.355 to 9.998) and (OR = 2.857; 95% CI 1.077 to 7.577). This result indicates that those drivers exposed to WBV at Dose 2 and Dose 6 at Q2 were 3.681 and 2.857 times likely to experienced LBP in comparison to those exposed at lower dose at Q1. The rest of the cumulative measures found to have no significant results. The results as presented in Table 4.36

Table 4.35: Dose Response Relationship Between WBV Daily Exposures and Symptoms of LBP

WBV exposures	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ Post Driving	
	n (%)	Crude OR (95% CI)	n (%)	Crude OR (95% CI)	n (%)	Crude OR (95% CI)
lna$_{ws}$						
Q_1 (n=37)	20 (54.1)	1.00	13 (35.1)	1.00	10 (27.0)	1.00
Q_2 (n=41)	24 (58.5)	1.200 (0.489 -2.942)	21 (51.2)	1.938 (0.779 – 4.822)	14 (34.1)	1.402 (0.530- 3.697)
Q_3 (n=39)	23 (59.0)	1.222 (0.443 -3.031)	14 (35.9)	1.034 (0.404 – 2.647)	7 (17.9)	0.591 (0.198 – 1.762)
Q_4 (n=38)	18 (47.4)	0.765 (0.309 -1.896)	9 (23.7)	0.573 (0.209 – 1.569)	7 (18.4)	0.610 (0.204 – 1.823)
lna$_{wq}$						
Q_1 (n=38)	18 (47.4)	1.00	13 (34.2)	1.00	10 (26.3)	1.00
Q_2 (n=40)	27 (67.5)	2.308 (0.921 -5.781)	23 (57.5)	2.602 (1.039 – 6.514) *	15 (37.5)	1.680 (0.640 – 4.409)
Q_3 (n=39)	21 (53.8)	1.296 (0.529 -3.174)	11 (28.2)	0.755 (0.287 – 1.987)	6 (15.4)	0.509 (0.164 – 1.577)
Q_4 (n=39)	19 (50.0)	1.111 (0.452 -2.733)	10 (26.3)	0.687 (0.256 – 1.839)	7 (18.4)	0.632 (0.212 – 1.886)
lnA(8)						
Q_1 (n=39)	21 (53.8)	1.00	16 (41.0)	1.00	12 (30.8)	1.00
Q_2 (n=38)	26 (68.4)	1.857 (0.733 - 4.705)	18 (47.4)	1.294 (0.525 – 3.187)	11 (28.9)	0.917 (0.345 – 2.434)
Q_3 (n=40)	19 (47.5)	0.776 (0.320 - 1.877)	15 (37.5)	0.863 (0.349 – 2.129)	8 (20.0)	0.563 (0.201 – 1.577)
Q_4 (n=38)	19 (50.0)	0.857 (0.350 - 2.097)	8 (21.2)	0.383 (0.140 – 1.050)	7 (18.4)	0.808 (0.175 – 1.474)
lnVDV						
Q_1 (n=38)	21 (55.3)	1.00	17 (44.7)	1.00	12 (31.6)	1.00
Q_2 (n=39)	22 (56.4)	1.048 (0.426 - 2.576)	18 (46.2)	1.059 (0.432 – 2.597)	14 (35.9)	1.213 (0.471 – 3.126)
Q_3 (n=39)	23 (59.0)	1.164 (0.472 - 2.872)	12 (30.8)	0.549 (0.216 – 1.396)	5 (12.8)	0.319 (0.100 – 1.018)
Q_4 (n=39)	19 (48.7)	0.769 (0.314 - 1.884)	10 (25.6)	0.426 (0.163 – 1.115)	7 (17.9)	0.474 (0.163 – 1.376)

* indicate statistically significant results

Table 4.36: Dose Response Relationship Between WBV Cumulative Exposures and Symptoms of LBP

WBV exposures	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ Post Driving	
	n (%)	Crude OR (95% CI)	n (%)	Crude OR (95% CI)	n (%)	Crude OR (95% CI)
Dose 1						
[lnT]	25 (61.0)	1.00	18 (43.8)	1.00	12 (29.3)	1.00
Q_1 (n=41)	21 (58.3)	0.896 (0.360 - 2.232)	17 (47.2)	1.143 (0.456 – 2.810)	12 (33.3)	1.208 (0.460 – 3.174)
Q_2 (n=36)	20 (51.3)	0.674 (0.277 -1.637)	14 (35.9)	0.716 (0.291 – 1.758)	9 (23.1)	0.725 (0.266 – 1.978)
Q_3 (n=39)	19 (48.7)	0.608 (0.250 -1.477)	8 (20.5)	0.330 (0.122 – 0.889)	5 (12.8)	0.355 (0.112 – 1.128)
Q_4 (n=39)						
Dose 2 $[\ln(a_{ws})T]$						
Q_1 (n=39)	21 (53.8)	1.00	13 (33.3)	1.00	8 (20.5)	1.00
Q_2 (n=39)	27 (69.2)	1.929 (0.763 – 4.872)	25 (64.1)	3.571 (1.401 - 9.083) *	19 (48.7)	3.681 (1.355 – 9.998) *
Q_3 (n=39)	18 (46.2)	0.735 (0.302 – 1.790)	12 (30.8)	0.889 (0.343 – 2.302)	5 (12.8)	0.570 (0.168 – 1.928)
Q_4 (n=38)	19 (50.0)	0.875 (0.350 – 2.097)	7 (18.4)	0.452 (0.157 -1.299)	6 (15.8)	0.727 (0.226 – 2.336)
Dose 3 $[\ln(a_{ws})^2T]$						
Q_1 (n=38)	20 (52.6)	1.00	13 (34.2)	1.00	9 (23.7)	1.00
Q_2 (n=40)	30 (75.0)	2.700 (1.036 – 7.037) *	26 (65.0)	3.571 (1.404 – 9.083) *	18 (45.0)	2.636 (0.996 – 6.978)
Q_3 (n=39)	19 (48.7)	0.855 (0.350 – 2.091)	13 (33.3)	0.962 (0.374 – 2.473)	7 (17.9)	0.705 (0.233 – 2.135)
Q_4 (n=38)	16 (42.1)	0.655 (0.265 – 1.619)	5 (13.2)	0.291 (0.092 - 0.925)	4 (10.5)	0.379 (0.106 – 1.360)
Dose 4 $[\ln(a_{ws})^4T]$						
Q_1 (n=38)	20 (52.6)	1.00	14 (36.8)	1.00	12 (31.6)	1.00
Q_2 (n=39)	26 (66.7)	1.800 (0.716 – 4.522)	20 (51.3)	1.805 (0.726 – 4.484)	12 (30.8)	0.963 (0.367 – 2.526)
Q_3 (n=39)	21 (53.8)	1.050 (0.429 – 2.571)	15 (38.5)	1.071 (0.426 – 2.695)	7 (17.9)	0.474 (0.163 – 1.376)
Q_4 (n=39)	18 (46.2)	0.771 (0.315 – 1.889)	8 (20.5)	0.442 (0.160 – 1.226)	7 (17.9)	0.474 (0.163 – 1.376)

Table 4.36: continued

WBV exposures	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ Post Driving	
	n (%)	Crude OR (95% CI)	n (%)	Crude OR (95% CI)	n (%)	Crude OR (95% CI)
Dose 5						
[ln(a_{wq})T]	20 (51.3)	1.00	14 (35.9)	1.00	9 (23.1)	1.00
Q_1 (n=39)	27 (71.1)	2.332 (0.910 – 5.976)	23 (60.5)	2.738 (1.088 – 6.888)	17 (44.7)	2.698 (1.011 – 7.202)
Q_2 (n=38)	20 (50.0)	0.950 (0.393 – 2.296)	13 (32.5)	0.860 (0.339 -2.180)	6 (15.0)	0.588 (0.187 – 1.846)
Q_3 (n=40)	18 (47.4)	0.855 (0.350 – 2.091)	7 (18.4)	0.403 (0.141 – 1.151)	6 (15.8)	0.625 (0.199 – 1.968)
Q_4 (n=38)						
Dose 6						
[ln(a_{wq})^{2}T]	19 (48.7)	1.00	12 (30.8)	1.00	9 (23.1)	1.00
Q_1 (n=39)	29 (74.4)	3.053 (1.175 – 7.928) *	26 (66.7)	4.500 (1.737 – 11.655) *	18 (46.2)	2.857 (1.077 – 7.577) *
Q_2 (n=39)	20 (52.6)	1.170 (0.478 – 2.860)	13 (34.2)	1.170 (0.450 – 3.040)	5 (13.2)	0.505 (0.152 – 1.677)
Q_3 (n=38)	17 (43.6)	0.813 (0.334 – 1.984)	6 (15.4)	0.409 (0.136 – 1.234)	6 (15.4)	0.606 (0.193 – 1.905)
Q_4 (n=39)						
Dose 7						
[ln(a_{wq})^{4}T]	21 (53.8)	1.00	15 (38.5)	1.00	11 (28.2)	1.00
Q_1 (n=39)	24 (61.5)	1.371 (0.557 – 3.378)	19 (48.7)	1.520 (0.618 – 3.739)	13 (33.3)	1.273 (0.485 – 3.338)
Q_2 (n=39)	23 (59.0)	1.232 (0.503 – 3.020)	16 (41.0)	1.113 (0.449 – 2.758)	7 (17.9)	0.557 (0.190 – 1.631)
Q_3 (n=39)	17 (44.7)	0.694 (0.283 – 1.702)	7 (18.4)	0.361 (0.127 – 1.026)	7 (18.4)	0.575 (0.196 – 1.687)
Q_4 (n=38)						

* indicate statistically significant results

4.3 Multivariate Analysis

In multivariate analysis, the symptoms of LBP were regressed against eleven parameter of vibration exposures in the log form i.e. a_{ws}, $a_{wq,}$ A(8), VDV, Dose 1 [total hours of exposure for total duration of employment (T)], Dose 2 [(a_{ws})T], Dose 3[$(a_{ws})^2$T], Dose 4 [$(a_{ws})^4$T], Dose 5 [(a_{wq})T], Dose 6 [$(a_{wq})^2$T] and Dose 7 [$(a_{wq})^4$T] adjusted for age, presence of MSD at other body region, involvement in part time job, smoking, work schedule, posture and alcohol consumption. These factors were selected for adjustment due to their significant association with LBP in the univariate analysis. Even though age did not have any significant association with LBP in univariate analysis, age was included in this analysis because it is a known confounding factors for development of LBP.

4.3.1 Dose Response Relationship between different measures of WBV exposures and symptoms of LBP

In general, the pattern of the odd for development of LBP were observed to increase from quartile one (Q1) as reference with lowest vibration dosage to quartile two (Q2). The pattern was suggestive that risks to have symptoms of LBP increasing with dose of vibration exposure. The increased odds of developing LBP were mostly observed from first quartile (Q1) to second quartile (Q2) of WBV in cumulative dosages with statistical significant result. Subsequently the odds were reducing in quartile three (Q3) to quartile four (Q4) as the highest vibration dosages. The higher the dosages it appears to dissolve the association. However, the results found to be not significant. The cumulative dose calculations following dose classified in Dose 2, Dose 3, Dose 5 and Dose 6 were found to be more predictive in the occurrence of LBP. The full results of these findings presented in Table 4.37 and Table 4.38.

4.3.1.1 Daily Exposures

There are four WBV exposures in daily measures expressed in $\ln a_{ws}$. $\ln a_{wq}$, $\ln A(8)$ and lnVDV. No statistical significant results were acquired to prove the dose response pattern using daily measure for occurrence of low LBP past 12 months, past four weeks and post driving. The full results of these findings presented in Table 4.37.

Table 4.37: Dose Response Relationship Between WBV Daily Exposures and Symptoms of LBP

WBV exposures	LBP @ past 12 months		LBP @ past 4 weeks		LBP @ post Driving	
	n (%)	aOR (95% CI)	n (%)	aOR (95% CI)	n (%)	aOR (95% CI)
lna$_{ws}$						
Q$_1$ (n=37)	20 (54.1)	1.00	13 (35.1)	1.00	10 (27.0)	1.00
Q$_2$ (n=41)	24 (58.5)	1.529 (0.576 – 4.054)	21 (51.2)	2.154 (0.831 – 5.584)	14 (34.1)	1.875 (0.651 – 5.406)
Q$_3$ (n=39)	23 (59.0)	1.321 (0.493 – 3.541)	14 (35.9)	0.943 (0.349 – 2.548)	7 (17.9)	0.683 (0.217 – 2.152)
Q$_4$ (n=38)	18 (47.4)	1.128 (0.429 – 2.967)	9 (23.7)	0.746 (0.260 – 2.143)	7 (18.4)	0.747 (0.235 – 2.369)
lna$_{wq}$						
Q$_1$ (n=38)	18 (47.4)	1.00	13 (34.2)	1.00	10 (26.3)	1.00
Q$_2$ (n=40)	27 (67.5)	2.107 (0.794 – 5.593)	23 (57.5)	2.350 (0.889 – 6.211)	15 (37.5)	1.838 (0.659 -5.130)
Q$_3$ (n=39)	21 (53.8)	1.197 (0.468 – 3.063)	11 (28.2)	0.650 (0.236 – 1.789)	6 (15.4)	0.566 (0.174 – 1.841)
Q$_4$ (n=39)	19 (50.0)	1.391 (0.541 – 3.572)	10 (26.3)	0.779 (0.287 – 2.221)	7 (18.4)	0.715 (0.228 – 2.238)
lnA(8)						
Q$_1$ (n=39)	21 (53.8)	1.00	16 (41.0)	1.00	12 (30.8)	1.00
Q$_2$ (n=38)	26 (68.4)	1.888 (0.714 – 4.996)	18 (47.4)	1.175 (0.459 – 3.009)	11 (28.9)	0.895 (0.315 – 2.541)
Q$_3$ (n=40)	19 (47.5)	0.912 (0.351 – 2.368)	15 (37.5)	0.888 (0.345 - 2.282)	8 (20.0)	0.579 (0.192 – 1.742)
Q$_4$ (n=38)	19 (50.0)	1.300 (0.493 – 3.430)	8 (21.2)	0.479 (0.165 – 1.392)	7 (18.4)	0.499 (0.164 – 1.520)
lnVDV						
Q$_1$ (n=38)	21 (55.3)	1.00	17 (44.7)	1.00	12 (31.6)	1.00
Q$_2$ (n=39)	22 (56.4)	0.927 (0.358 – 2.401)	18 (46.2)	0.888 (0.346 -2.278)	14 (35.9)	1.057 (0.388 – 2.882)
Q$_3$ (n=39)	23 (59.0)	1.114 (0.428 – 2.898)	12 (30.8)	0.466 (0.174 – 1.245)	5 (12.8)	0.324 (0.096 – 1.090)
Q$_4$ (n=39)	19 (48.7)	0.953 (0.371 – 2.446)	10 (25.6)	0.466 (0.171 – 1.272)	7 (17.9)	0.463 (0.153 – 1.403)

*****indicate statistical significant finding

**(adjusted for age, presence of MSD at other body region, involvement in part time job, smoking, work schedule, posture and alcohol consumption)

4.3.1.2 Cumulative Exposures

There are seven WBV exposures in cumulative measures expressed as Dose 1[lnT], Dose 2 [ln(a_{ws})], Dose 3 [ln(a_{ws})^{2}T], Dose 4 [ln(a_{ws})^{4}T], Dose 5 [ln(a_{wq})], Dose 6 [ln(a_{wq})^{2}T] and Dose 7 [ln(a_{wq})^{4}T]. Generally, the cumulative measures showed statistical significant results to prove on the dose response pattern. Refer in Table 4.38 for full results.

a) Low Back Pain past twelve months

Using the cumulative measures, the odds for development of LBP (in comparison with the reference group) of Dose 3 and Dose 6 [ln(a_{ws})^{2}T and ln(a_{wq})^{2}T] for drivers in Q2 (aOR = 2.822; 95% C1 1.038 to 7.668) and (aOR = 2.981; 95% CI 1.096 to 8.104) respectively. The finding indicate that drivers received WBV exposure in Dose 3 and Dose 6 at Q2 were 2.822 and 2.981 times likely to developed LBP in comparison to those received lower dose at Q1. The rest of the cumulative measures found to have no significant results.

b) Low Back Pain past four weeks

The statistical significant results for the development LBP were observed at Q2 with odds (aOR= 3.667; 95% CI 1.399 to 9.613) and (aOR= 2.649; 95% CI 1.206 to 6.838) for cumulative measures for exposure in Dose 2 and Dose 5 [ln(a_{ws})T and ln(a_{wq})T] and (aOR = 3.303; 95% CI 1.273 to 8.570) and (aOR = 3.852; 95% CI 1.455 to 10.193) using Dose 3 dan Dose 6 [ln(a_{ws})^{2}T and ln(a_{wq})^{2}T] respectively. The finding indicates that the drivers with cumulative exposure in Dose 2 and Dose 5 [(a_{ws})T and (a_{wq})T] at Q2 were 3.667 and 2.649 times likely to developed LBP in comparison to those at Q1. Similar trend for cumulative exposure in Dose 3 and Dose 6 [(a_{ws})^{2}T and (a_{wq})^{2}T] were 3.303 and 3.852 times likely to developed LBP for those received dose at Q2. The total accumulated hours of exposure given in Dose 1 [lnT] and Dose 4 and Dose 7 [$\ln(a_{ws})^4T$ and $\ln(a_{wq})^4T$] respectively found to have no significant finding.

c) Low Back Pain at Post Driving

In the cumulative measures only one statistical significant result observed at Q2 for WBV exposure in Dose 2 [$\ln(a_{ws})T$] with (aOR = 4.208; 95% CI 1.442 to 12.277). This result indicates that those drivers exposed to WBV at Q2 were 4.208 times likely to developed LBP in comparison to those exposed at lower dose at Q1. The rest of the cumulative measures found to have no significant results.

Table 4.38: Dose Response Relationship Between WBV Cumulative Measures and Symptoms of LBP

WBV exposures	LBP @ past 12 months		LBP @ past 4 weeks		LBP @ post driving	
	n (%)	aOR (95% CI)	n (%)	aOR (95% CI)	n (%)	aOR (95% CI)
Dose 1 [lnT]						
Q_1 (n=41)	25 (61.0)	1.00	18 (43.8)	1.00	12 (29.3)	1.00
Q_2 (n=36)	21 (58.3)	1.128 (0.425 – 2.999)	17 (47.2)	1.309 (0.507 – 3.380)	12 (33.3)	1.304 (0.469 -3.629)
Q_3 (n=39)	20 (51.3)	1.945 (0.350 – 2.522)	14 (35.9)	0.817 (0.313 – 2.135)	9 (23.1)	0.667 (0.231 -1.927)
Q_4 (n=39)	19 (48.7)	1.080 (0.343 – 3.403)	8 (20.5)	0.407 (0.142 – 1.168)	5 (12.8)	0.367 (0.108 – 1.245)
Dose 2 [ln(a_{ws})T]						
Q_1 (n=39)	21 (53.8)	1.00	13 (33.3)	1.00	8 (20.5)	1.00
Q_2 (n=39)	27 (69.2)	2.426 (0.897 – 6.556)	25 (64.1)	3.667 (1.399 – 9.613) *	19 (48.7)	4.208 (1.442 – 12.277) *
Q_3 (n=39)	18 (46.2)	1.211 (0.429 – 3.421)	12 (30.8)	0.873 (0.315 – 2.228)	5 (12.8)	0.557 (0.156 – 1.988)
Q_4 (n=38)	19 (50.0)	1.811 (0.568 – 5.770)	7 (18.4)	0.466 (0.158 – 1.372)	6 (15.8)	0.842 (0.244 – 2.899)
Dose 3 [ln(a_{ws})^{2}T]						
Q_1 (n=38)	20 (52.6)	1.00	13 (34.2)	1.00	9 (23.7)	1.00
Q_2 (n=40)	30 (75.0)	2.822 (1.038 – 7.668) *	26 (65.0)	3.303 (1.273 -8.570) *	18 (45.0)	2.468 (0.888 – 6.861)
Q_3 (n=39)	19 (48.7)	1.070 (0.407 – 2.809)	13 (33.3)	0.866 (0.329 – 2.281)	7 (17.9)	0.675 (0.213 – 2.145)
Q_4 (n=38)	16 (42.1)	0.921 (0.349 – 2.436)	5 (13.2)	0.301 (0.093 – 0.970)	4 (10.5)	0.378 (0.098 – 1.454)
Dose 4 [ln(a_{ws})^{4}T]						
Q_1 (n=38)	20 (52.6)	1.00	14 (36.8)	1.00	12 (31.6)	1.00
Q_2 (n=39)	26 (66.7)	1.862 (0.693 – 4.999)	20 (51.3)	1.571 (0.605 – 4.078)	12 (30.8)	0.757 (0.269 – 2.129)
Q_3 (n=39)	21 (53.8)	1.492 (0.520 – 4.283)	15 (38.5)	1.053 (0.393 – 2.828)	7 (17.9)	0.476 (0.152 – 1.493)
Q_4 (n=39)	18 (46.2)	1.387 (0.483 – 3.985)	8 (20.5)	0.566 (0.192 – 1.671)	7 (17.9)	0.465 (0.152 -1.424)

Table 4.38: Continued

Dose	LBP @ past 12 Months		LBP @ past 4 Weeks		LBP @ Post Driving	
	n (%)	aOR (95% CI)	n (%)	aOR (95% CI)	n (%)	aOR (95% CI)
Dose 5 [ln(a_{wq})T]						
Q_1 (n=39)	20 (51.3)	1.00	14 (35.9)	1.00	9 (23.1)	1.00
Q_2 (n=38)	27 (71.1)	2.526 (0.942 - 6.776)	23 (60.5)	2.649 (1.206 – 6.838) *	17 (44.7)	2.802 (0.989 – 7.936)
Q_3 (n=40)	20 (50.0)	1.181 (0.455 – 3.063)	13 (32.5)	0.763 (0.292 – 1.990)	6 (15.0)	0.521 (0.157 – 1.732)
Q_4 (n=38)	18 (47.4)	1.230 (0.469 – 3.229)	7 (18.4)	0.414 (0.142 – 2.208)	6 (15.8)	0.704 (0.209 – 2.377)
Dose 6 [ln(a_{wq})^{2}T]						
Q_1 (n=39)	19 (48.7)	1.00	12 (30.8)	1.00	9 (23.1)	1.00
Q_2 (n=39)	29 (74.4)	2.981 (1.096 – 8.104) *	26 (66.7)	3.852 (1.455 – 10.193) *	18 (46.2)	2.336 (0.853 – 6.396)
Q_3 (n=38)	20 (52.6)	1.337 (0.514 – 3.480)	13 (34.2)	1.002 (0.375 -3.673)	5 (13.2)	0.410 (0.119 – 1.406)
Q_4 (n=39)	17 (43.6)	1.086 (0.420 – 2.809)	6 (15.4)	0.399 (0.130 – 1.222)	6 (15.4)	0.595 (0.185 – 1.910)
Dose 7 [ln(a_{wq})^{4}T]						
Q_1 (n=39)	21 (53.8)	1.00	15 (38.5)	1.00	11 (28.2)	1.00
Q_2 (n=39)	24 (61.5)	1.561 (0.598 – 4.075)	19 (48.7)	1.499 (0.582 -3.856)	13 (33.3)	1.086 (0.393 – 3.002)
Q_3 (n=39)	23 (59.0)	1.780 (0.632 – 5.009)	16 (41.0)	1.135 (0.431 – 2.987)	7 (17.9)	0.584 (0.187 – 1.822)
Q_4 (n=38)	17 (44.7)	1.267 (0.451 – 3.560)	7 (18.4)	0.480 (0.158 – 1.453)	7 (18.4)	0.583 (0.190 – 1.797)

*indicate statistical significant finding

**(adjusted for age, presence of MSD at other body region, involvement in part time job, smoking, work schedule, posture and alcohol consumption)

4.4 Summary of Results

1. The WBV exposure analyze according to types of vehicles revealed that:

   i. Based on measurement reported in a_{ws} and a_{wq} the higher acceleration magnitude were the garbage compactor truck, lorry and fire fighter truck.

   ii. Based on measurement reported in daily dose A(8) and VDV those produce higher doses were the garbage compactor truck, lorry and bus.

2. Selection of WBV evaluation methods either basic evaluation (r.m.s) or additional evaluation (r.m.q) influences the level and severity of exposure. Monitoring using the VDV tended to give dominated results of reading exceeded HGCZ as recommended by the ISO 2631-1:1997 hence indicated with the likelihood of health risks as opposed to the A(8) which about half give reading below the HGCZ imposed minimal or no health risks involved.

3. The risks factor associated with LBP at various time points at univariate analysis were:

Categories	Descriptions
Positive Association	• Educational achievement (educated drivers tend to report more occurrence of LBP) • Presence of MSD other than low back region (drivers experienced MSD at other body region tend to report more occurrence of LBP) • Involvement of part time job (drivers involved in part time job tend to report more occurrence of LBP)
Negative Association	• Alcohol consumption (alcoholic drivers reported with less occurrence of LBP) • Posture adapted while driving (drivers adapted torso straight reported with less occurrence of LBP) • Working schedule (drivers on shifts or other job schedule reported with less occurrence of LBP).

4. The risks factors associated with LBP at various time points using simple logistic regression analysis were:

Categories	Descriptions
Positive Association	• Higher education increased the odds for development of LBP among the drivers. The odds documented ranged from (OR = 5.133 to 12.461). • Presence of other MSD increased the odds for development LBP among the drivers. The odds documented ranged from (OR = 2.042 to 2.804) • Involvement in part time job increased the odds for development of LBP among the drivers. The odds documented ranged from (OR = 2.365 to 2.824) • Smoking increases the odds for development of LBP among the drivers. The odds documented ranged from (OR = 3.845 to 3.938)
Negative Association	• Alcohol intake lower the risks associated with LBP as odds documented ranged from (OR = 0.392 to 0.306). • Adaptation of torso straight while driving lower the risks associated with LBP as odds documented of (OR = 0.371) • The work schedule following shift lower the risk associated with LBP with odds documented ranged from (OR = 0.349 to 0.354)

5. Analysis of the dose response relationship between exposures of WBV dosage with symptoms of LBP at various time points. The cumulative dose calculations were more predictive in association with LBP in comparison to the daily dose calculation

Categories	Descriptions
Daily Doses	• Multivariate logistic regression model adjusted for significantly associated risks factor showed no statistical significant results indicated for dose response relationship.
Cumulative Doses	• Indication of dose response with statistical significant results observed mostly at Q2 (the odds for symptoms of LBP increased when the dose of exposure increased from Q1 to Q2) in the final multivariate logistic regression model after adjustment with associated risks factor. The effect of dose response disappeared from Q3 to Q4 however the finding was not significant. • The calculation of Dose 2 $[(a_{ws})T]$ Dose 5 $[(a_{wq})T]$, Dose 3 $[(a_{ws})^2T]$ and Dose 6 $[(a_{wq})^2T]$ of cumulative measures seems to be more sensitive and produce the statistical significant results in the final model. • Symptoms of LBP occurred past four week revealed more statistical significant results as it reduces the effect of recall bias in comparison to the symptoms occurred past twelve months and post driving.

CHAPTER 5: DISCUSSIONS

5.1 Characteristics of Respondents

5.1.1 Socio-demographic Characteristics

The participants were staffs from various departments (government and private sector) located mostly at east coast region of Sabah and work description as a driver. Majority of the drivers come from local ethnicity namely the Kadazan/Dusun and Bajau. The racial distribution was expected as the two mentions were the largest ethnicity group in the state of Sabah.

Our drivers were dominated by male, which was expected. Selection on job preference influences by certain factors (Hosada, Stone, & Stone-Romero, 2003) suggested that selection decisions might be jointly determined by race, gender and the nature of the job. Furthermore, males and females differed on the three of the four jobs attribute categories; career orientation, work conditions and parental support and that female experience mora role conflict than males (Wiersma, 1990). Women were often assigned less physically strenuous job in many workplaces in comparison to male worker (Hooftman et al, 2005). Thus, certain types of occupation were more preponderance to certain gender, especially those jobs involving heavy work load. However small proportion of female bus drivers were reported in study conducted in Hong Kong (Szeto & Lam, 2007), female tractor driver in Sweden (Torén et al., 2002), female urban taxi driver in Taiwan (Chen et al., 2005) and female truck driver in Japan (Miyamoto et al., 2008).

The mean (SD) age of drivers participated in our study was 39.81 (9.17) ranging from 24 to 68 years. Studies that conducted in the past reported mean age of drivers were mostly in their thirties to forties (Begum et al., 2012; Chen et al., 2005; Miyamoto et al., 2008; Samuel & Babajide, 2012; Szeto & Lam, 2007; Tamrin et al., 2007). The youngest mean age of 29.8 (4.9) years were documented among the military armoured vehicle in Malaysia (Rozali et al., 2009) and the oldest mean age of 51.5 (9.5) observed among taxi drivers in Japan (Miyamoto et al., 2008)

Based on education, monthly income and marital status upon comparison to other local studies among drivers in Malaysia showed that the income from our participants was higher than the bus driver in the peninsular (Tamrin et al., 2007) and military armour driver (Rozali et al., 2009) while for the level of education and marital status, majority of them were married and completed secondary school as finding were consistent with both reported from the two studies mentions. However, in our participants, those achieved tertiary education were slightly higher with 8.4% as opposed to finding among bus driver with 2.5% (Tamrin et al., 2007)

Generally, in our local set up, to fill up the post as a driver in government facilities, the applicant required to achieve lower secondary school. This is the basic qualification needed according to the Public Services Commission of Malaysia (http://www.spa.gov.my). Overall the sociodemographic characteristics of our drivers were comparable to the population of drivers in previous studies.

5.1.2 Lifestyles Characteristics

The prevalence of smoking among our drivers was 49.6%, slightly higher in comparison to the data reported in National Health Morbidity Survey (NHMS) (Ministry of Health Malaysia, 2015) for the prevalence of smoking among male of 43.0%. Furthermore, Sabah and Wilayah Persekutuan Labuan were reported to have highest overall prevalence of adult smoking of 28.4%, hence the higher prevalence of smoking among our drivers was expected in comparison to national level. Comparing the habit of smoking among drivers from our studies, showed almost similar finding of 41.4% of smoker among professional drivers in Dhaka Bangladesh (Begum et al., 2012) but lower in comparison to the rate of 68.3% as a smoker in a study conducted among Iranian professional drivers (Mohebbi et al., 2012). However, there are studies that revealed more number of nonsmokers among their drivers group (Rose & Wojcik, 2015; Torén et al., 2002)

The rate of those performing adequate exercise was 41.3% among our participants, which was comparable to those reported in the NHMS (Ministry of Health Malaysia, 2015). Nevertheless, when compared to male population only the prevalence among our participants were lower. There are studies reported that drivers did not performed adequate exercise as per recommendation (Rose & Wojcik, 2015; Turner & Reed, 2011).

More than half of our participants were nonalcoholic, lower in comparison to data from NHMS (Ministry of Health Malaysia, 2015) where lifetime abstainers were 85.5%. The proportion of alcohol consumption in our participants were comparable with NHMS (Ministry of Health Malaysia, 2015), however the proportion of occasional drinker or ever consume alcohol were higher. Lower nonalcoholic rate and higher occasional drinker rates among our drivers can be partially explained by the racial distribution in Sabah. The habit of consuming alcohol among drivers reported with variation in different countries. In Sri Lanka about 34% of the three-wheeler drivers were nonalcoholic (Noda et al., 2015) 52.6% among truck drivers in Brazil were nonalcoholic (Andrusaitis et al., 2006) and 73% of student truck drivers in New Zealand either not consume alcohol or are light drinkers (Rose & Wojcik, 2015).

5.1.3 Personal and Health Related Characteristics

The mean (SD) height of 165.6 (7.7) cm and weight of 73.0 (12.6) kg of our driver population were comparable to the height of the drivers group from the studies conducted in Japan, height 167.1 (6.1) cm, weight 66.1(9.8) kg (Miyamoto et al., 2008)and in Hong Kong, height 167.7 (5.92), weight 71.1 (10.5) (Szeto & Lam, 2007) but our drivers were heavier comparatively.

The means BMI reported in our drivers of 26.7 kg/m^2 comparable to the means BMI reported among drivers in other studies in Asian region ranged between 21 kg/m^2 to 25 kg/m^2 (Begum et al., 2012; Chen et al., 2005; Miyamoto et al., 2008, 2000; Szeto & Lam, 2007). The distribution of more drivers fall under overweight and obese noticed to be more prominent in developed nation reported on BMI among the commercial truck driver in the United States with 93.3% of BMI $\geq$ 25 (Turner & Reed, 2011)

About 19.4% of our drivers reported with past medical history. The two most common diseases reported were hypertension and diabetes. Undeniable that diabetes and hypertension are the two most common non-communicable diseases that are quite prevalent among Malaysian population in general. The prevalence for both disorders based on male population was 30.8 for hypertension and 16.7% for diabetes (Ministry of Health Malaysia, 2015). The proportions being observed in our male drivers revealed that out of 30 drivers with past medical history 19 (63.3%) had hypertension and 7 (23.3%) had diabetes. The proportions of those diagnosed with hypertension and diabetes among our male drivers were higher in comparison. It is not surprising to see such pattern, as professional drivers are prone to metabolic syndrome and its complications because of their working environment is characterized by numerous stress factors such as lack of physical activity due to working in fixed position for long hours, cigarette smoking, job stress, unhealthy diet and irregular sleep habits (Mohebbi et al., 2012)

The proportion of drivers reported with occurrence of LBP at twelve months prior were 54.8%, four weeks prior 36.8% and post driving 24.5% in our study. Although, cautions have to be exercise when comparing the prevalence of low back especially the definition that being used.

Study in the past reported the rate of occurrence for LBP at 12 months falls between 50 % - 80 %. The reported prevalence among military wheeled armoured vehicles drivers in Malaysia was 67.0% (Rozali et al., 2009), taxi drivers in Taiwan with reported prevalence of 51.0% (Chen et al., 2005), reported prevalence of 78.0% among professional car drivers in Dhaka City, Bangladesh (Begum et al., 2012) and prevalence of 82.9% among bus driver and tractor driver of 71.7% in Italy (Bovenzi, 1996).

Some authors preferred to report the prevalence of low back pain among drivers based on the occurrence of low back pain at shorter duration prior to data collection. This action intended to reduce the recall bias, as if the occurrence of pain happens within one month prior the respondent could remember better of the symptoms. The occurrence of pain at four weeks by (Miyamoto et al., 2000) reported 50.3% among truck drivers which indicate high values in comparison to our study. Another study showed one week prevalence of low back pain was 20.5% among taxi drive in Japan (Miyamoto et al., 2008). We did not report on occurrence of pain at one week as the possibility that we might not able to capture those experience pain and taking medical leave for that matter during the data collection. Despite that we can conclude that if shorter time frame being used fewer respondents documented with symptoms of LBP. Prevalence of LBP post driving was 36.5% comparatively higher than the values from our current study (Tiemessen et al., 2008).

Apart for experienced LBP the drivers also admitted having MSD other than low back region. The region of shoulder (33.7%), knee (28.5%), neck (16.8%) and upper back (9.1%) were the four most common regions with MSD reported among our drivers. The occurrence of MSD other than low back region were comparable among the bus drivers in Peninsular Malaysia who experienced pain in the region of neck, upper back and shoulder (Tamrin et al., 2007). Similarly the bus drivers in Hong Kong reported pain the region of neck, shoulder and knee/thigh (Szeto & Lam, 2007). Occupation as a drivers seen as vulnerable for many ailments thus apart from musculoskeletal disorders, the health compromising issues for trucker include psychological and psychiatric disorders, disrupted biological cycles, cancer and respiratory morbidities, risk-laden substance use and sexual practices (Apostolopoulos et al., 2010). Even so, in this report we only concentrate on analyzing the adverse impact of musculoskeletal disorder especially the low back area.

5.1.4 Occupational Details

5.1.4.1 Vehicles Characteristics

The types of vehicles included in our study mostly operating on paved road with eight different sub classifications. It was intended to get variety of vehicles hence it gives wide variation and intensity of WBV exposure. However, the specific types of vehicles such as multipurpose vehicles (MPV), ambulance, fire fighter truck and sport utilities vehicles (SUV) were among the types with no specific study found for comparison. Certain types of vehicles were investigated thoroughly in case of bus, taxi, truck, lorry and garbage compactor/truck. Studies conducted elsewhere for the evaluation of whole body vibration demonstrated with wide variation of vehicles, namely bus (Bovenzi & Zadini, 1992; Fadhli et al., 2016; Lewis & Johnson, 2012; Okunribido et al., 2007a; Szeto & Lam, 2007; Tamrin et al., 2007; Thamsuwan et al., 2013) trolley bus (Dundurs, 2001), terrain vehicles (ATVs) that further classify as snow groomer, snowmobiles and forwarders (Borje Rehn, Lundstrom, Nilsson, Liljelind, & Jarvholm, 2005), agricultural tractor (Boshuizen et al., 1990; Bovenzi, 1996; Bovenzi & Betta, 1994; Kumar et al., 1999; Lines et al., 1994; Torén et al., 2002), load-haul-dump mining vehicles (Eger et al., 2008), heavy equipment mining vehicles (Johnson et al., 2015; Marin et al., 2016), heavy equipment vehicles further subdivided into forklift, crane, tractor, earth moving (Waters, Genaidy, Viruet, & Makola, 2008), truck (Miyamoto et al., 2000), there tone army truck (Aziz et al., 2014), armoured vehicles (Rozali et al., 2009), long-haul truck (Kim et al., 2015), forklift truck (J. Hoy et al., 2005), rally vehicles (Mansfield & Marshall, 2001), taxi (Chen et al., 2004; J. C. Chen et al., 2003; Chen et al., 2005; Miyamoto et al., 2008;

Samuel & Babajide, 2012), solid waste collection truck (Paschold, 2015), railroad locomotives (Johanning et al., 2002). Some authors combined different types of vehicles in one particular study such as bus and tractor (Bovenzi, 1996), police driver, tractor, truck, van, bus, taxi (Okunribido et al., 2006), earth moving machine, articulated dumper, off road car, forklift truck, track type loader, freight container tractor, mobile crane, garbage truck, garbage compactor, bus (Bovenzi, 2010), vehicles used in marble quarries, marble laboratories, dockyards, paper mills, public utilities and public transport (Bovenzi, 2009; Bovenzi et al., 2006b), wheeled loader, lawn moving machine, bulldozer, tractor, excavator, lorry, dumper, steamroller, crane, asphalt machine (Tiemessen et al., 2008) and fork lift truck, truck, heavy machinery (Schwarze et al., 1998). Other authors reported based on types of occupation instead of assigning according to types of vehicles operated such as the driving police officer (Gyi & Porter, 1998) and delivery driver (Okunribido et al., 2006). As we can see from this data, most of the author put their major concern studying the heavy vehicles mainly used off-road. However, the increase in the number of light and medium size vehicles operated on road deserved equal attention.

Based on manufacturing years, about 47.1% of our vehicles already in used for six to ten years, and about 14.2% exceeded 10 years in service comparatively another study reported that 34% of their vehicles used for approximately seven to nine years and 30% exceeded 10 years (Chen et al., 2003). It is common to see vehicles that already in service above than five years in transportation industry. Budget constraint become the main reason for not able to replace the vehicles regularly. Despite, the maintenance was strictly being monitor and done according to schedule. This action at least preserves the condition of vehicles. In summary, the current state and conditions would influence the vibration produce by vehicles, furthermore the older version may not equip with technologist that protect the drivers.

Most of our vehicle used manual gear transmission (81.3%) whereas study conducted by Chen et al, 2003 dominated with vehicles using the automatic transmission (63%) (Chen et al., 2003). The types of gear transmission influenced the posture of the driver. The manual transmission requires the driver to utilize more of their upper and lower limbs while changing the gear to adjust the speeding. It involved constant movement of other body regions that may cause or aggravate musculoskeletal disorders.

5.1.4.2 Work Characteristics

Most of the data collection centers are a government statuary body except for the Taxi and Limousine Association of KKIA (Kota Kinabalu International Airport) which operate as a privatize companies. Only drivers hired as permanent worker included in our study.

More than half of our drivers working according to shift schedule. Similar results have been reported among the bus drivers (Tamrin et al., 2007). The taxi drivers from our study were working on their own hence they were free to select their own schedule. However, they opted to take more hours of working as means to gain more income.

More than half of our drivers were doing outstation duty which we did not able to find any data to compare. The impact of doing outstation predisposed them with different road surfaces that directly could affect the exposure towards whole body vibration.

Majority of our participants had history of involving in previous job before starting their career as a driver in their current post, about half of the previous job was driving related.

Involvement of part time job among our drivers (21.9%) was higher comparatively to the study conducted in Peninsular Malaysia (6.4%) (Tamrin et al., 2007) The part time job reported mostly not related to driving.

5.1.4.3 Work Duration

The working hours in Malaysia were regulated according to the Work Act (*Akta Kerja 1955 Seksyen 60 (A)).* According to this act, the hours of work defined as the time during which an employee is at the disposal of the employer and is not free to dispose of his own time and movements. The working hours in Malaysia are eight hours per day/shift with one-hour provision for resting.

However, the means hours of working per day/shifts documented among our drivers was 10.0 ± 3.1 hours. The hours of working were more or less similar with other studies as mean of daily working hours of 12.3 (5.2) among taxi drivers in Japan (Miyamoto et al., 2008) and mean of daily working hours of 9.95 (1.02) among urban bus drivers in Hong Kong (Szeto & Lam, 2007). In Nigeria about 42% of the sample of taxicabs drivers reported always or often spends/works more than 8 hour/day (Samuel & Babajide, 2012). The longer duration of working per days causing induced fatigue as drivers may not enough time to rest.

The duration of driving in our study were documented in hours per day, hours per week and hours per months. Means (SD) duration of driving per day was 4.9 (1.8), driving per week was 36.1 (15.2) hours and driving per month was 152.8 (64.8) hours. In comparison, duration of driving per day/shift among our respondent were lower as other study reported a daily driving hours of 9.8 (2.8) among urban taxi driver (Chen et al., 2005) and average hours driving of 10.52 (0.13) among bus driver per day (Tamrin et al., 2007). Drivers in our groups come from many sectors, hence we expected the variation of time spend driving per day/shift. The shorter hours of driving among our respondents can be explained as some of them worked on standby basis such as the ambulance and fire fighter truck drivers. As an example, the variation of average daily routine driving ranged from one hour 40 minutes up to 8.5 (3.8) hours during military exercise (Rozali et al., 2009). This example showed that duration of driving per days for each driver varies according to the job assignment given, however this can be an isolated case as most of the time they have fixed schedule. Even though the daily driving exposures among our respondents were lower, however the risks to get LBP is higher when the drivers work about 30 – 50 hours per week compared with the drivers who works less than 30 hours (Fadhli et al., 2016). This showed that our drivers at risks because the means hours of driving per week exceeded 30 hours.

The mean (SD) duration of employment as current post as driver was 8.4 (7.5) year comparable to duration of employment of eight years among bus driver in Peninsular Malaysia (Tamrin et al., 2007). Meanwhile, the mean duration for total years of employment as driver was 12.7 (9.3). The total years of employment included those years of involvement in previous job related to driving or involvement in part time job related to driving. Other studies conducted among drivers elsewhere reported on ranged from 10 to 12 years of seniority with duration of taxi driving was 11.4 (7.8) years in Taiwan (Chen et al., 2004), average length of service was 14.1 (12.1) years among taxi drivers in Japan (Miyamoto et al., 2008), mean working years was 13.01 (8.90) among urban bus drivers in Hong Kong (Szeto & Lam, 2007) and number of years of driving among the professional car drivers in Bangladesh was 12.68 (6.67) (Begum et al., 2012)

The accumulated mileage from our drivers were comparable from study conducted in Taiwan with daily driving distance of 184 (47) (Chen et al., 2004) and monthly mileage of 3416.4 (1115.7) km among respondents of taxi drivers in Japan (Miyamoto et al., 2008).Based on the days of working per months reported mean of 25.5 (5.1) in our study, were almost similar with number of days working per months of 26.2 (2.6) among taxi drivers in Taiwan (Chen et al., 2005).

5.1.4.4 Work Habit

The drivers were also being evaluated on their work habits, about half of them (41.9%) took rest of less than 15 minutes and about 7.1% admitted that they drove exceeded four hours before resting. These habits predispose the drivers to have longer exposure of whole body vibration that might enhance their effect to develop the symptoms of low back pain. The means duration of deriving per route among the bus drivers in Hong Kong was 60.54 (20.32) minutes, they were needed to take two route before resting which in turn they were continuously driving equivalent to two hours before resting with means resting time taken of 7.87(5.20) minutes (Szeto & Lam, 2007).

5.1.4.5 Other Physical Exposure at Work

Apart for WBV, the drivers also exposed to other occupational risks factor namely material manual handling (MMH) and postural load. About 92.3 % of our drivers reported to deal with material manual handling as part of their routine. Our data were higher comparatively, with only 41% performing manual handling among taxi driver (Chen et al., 2005) but comparable to those reported with 98% and 70.4% performing manual lifting (equipment) and pushing and pulling equipment respectively among armour vehicles drivers (Rozali et al., 2009)

Driving in confined spaces predispose them with poor and static posture for longer period of time. Through postural assessment our drivers mostly adapted the torso against backrest (61.3%), however the adaptation of posture may vary due to types of vehicles. Those drivers drove huge vehicles need to bend forward for a better view, thus mostly adapting the forward bending posture (74.8%) (Rozali et al., 2009). While driving a vehicle, drivers also need to tilt, bend and twist their torso but reported with minimal involvement of 10.3% (Chen et al., 2005) which comparable to our data.

5.2 WBV exposures assessment among Respondents

5.2.1 Descriptions on WBV Exposures

The WBV exposures among drivers were evaluated according to the acceleration magnitude then subsequently the calculation of WBV dosages. The data obtained used to describe the pattern of WBV produced by different types of vehicles involved in this study.

5.2.1.1 Crest Factor

In our current study about half of crest factor (CF) values exceeded nine observed mostly at vibration reported in z-axis. Monitoring of CF values exceeded nine indicate the need to include the additional evaluation methods. The finding of CF values exceeded nine were common. The values of CF for the army three tone truck driver in Malaysia showed that most of the CF values are higher than nine, while most of the others are very close to nine (Aziz et al., 2014) while monitoring of the seven load-haul-dump (LHD) mining, every LHD vehicle had at least one CF value above nine (Eger et al., 2008) and CF were generally higher than nine in x and z direction for the assessment of the railroad locomotives (Johanning et al., 2002).

The road surfaces condition in Sabah could affect the values of CF recorded in our current study. Hence the high values of CF were expected as the rough road surfaces produce frequent shocks. The values of CF also affected by various factors among identified are the road surfaces. Travelled on cobble tended to associate with considerably high CF values above nine which indicate that the vibrations in these conditions included severe shocks (Okunribido et al., 2006).

5.2.1.2 Basic Evaluation and Additional Evaluation

The domination of z-axis for the WBV monitoring was common finding reported from many studies (Bovenzi, 2009, 2010; Bovenzi & Zadini, 1992; Johnson et al., 2015; Kim et al., 2015; Lewis & Johnson, 2012) which is comparable to our data. However, study conducted in automated residential solid waste collection showed that the x and y-axis levels are higher during collection then while driving, z-axis values are lower in collection than driving (Paschold, 2015). Thus, the dominant axis varies and determined by the speed of the vehicles.

Another study reported the predominant axis of vibration exposure was related and dependent on types of Heavy Equipment Mining Vehicles (HEVs), which all have different average speeds, slowest HEVs (below 3.0 km/h), the for-aft x-axis exposure predominate, intermediate speed HEVs (6-12 km/h) predominate by side to side y-axis and the speed above 12km/h the vertical up and down z-axis predominate the exposure (Marin et al., 2016). The measurement of WBV in our current study only concentrate while the vehicles is on moving, hence expectation that the z-axis predominate as the vehicles is used with certain speed limit. However, there is condition while operating a vehicle that can reduce the speed such as when reversing the car or idling when stuck in traffic jam, this condition might produce variation in the predominant axis that might not captured during measurement.

The finding from other studies that reported their acceleration values in x, y and z-axis according to types of vehicles was compared accordingly. Only the bus, lorry, taxi and garbage compactor truck were the types of specific vehicles with available data for comparison.

The means weighted acceleration for our buses in x-axis ranged from 0.22 to 0.25, y-axis ranged from 0.19 to 0.20 and z-axis ranged from 0.37 to 0.43 expressed in r.m.s. Study among the urban bus drives in Italy (Bovenzi, 1996; Bovenzi & Zadini, 1992) revealed that the weighted r.m.s acceleration through the seat pan monitoring with x-axis ranging from 0.05 to 012, y-axis ranging from 0.05 to 0.16 and z-axis ranging from 0.22 to 0.65. The documented weighted acceleration in x and y-axis were higher comparatively but the z-axis was comparable. Another acceleration data for bus conducted in Peninsular Malaysia, reported the mean values of x, y and z-axis in three regions with [x-axis: 0.08 (Central), 0.07 (Eastern), 0.19 (Northern)], [y-axis: 0.08 (Central), 0.07 (Eastern), 0.21 (Northern)], [z-axis: 0.26 (Central), 0.18 (Eastern), 0.39 (Northern)] (Tamrin et al., 2007). The reading from our buses was almost similar to the reading that was gathered from the Northern region covering the states of Perak, Kedah, Penang and Perlis. Another study in Scotland, with comparatively higher acceleration for bus with r.m.s accelerations ranged between 0.029 and 0.449 in the x-axis, between 0.046 and 0.470 in the y-axis and between 0.100 and 1.01 in the z-axis (Okunribido, Shimbles, Magnusson, & Pope, 2007b).

The means weighted acceleration for our lorry in x-axis was 0.24 to 0.25, y-axis from 0.23 to 0.26 and z-axis from 0.66 to 0.77 expressed in r.m.s. Our data were comparable to the reading gathered from direct measurement of the delivery vehicles with that mean average r.m.s acceleration ranged between 0.09 and 0.51 in the x-axis, between 0.11 and 0.45 in the y-axis and between 0.12 and 0.60 in the z-axis (Okunribido et al., 2006).

The types of vehicles classify under garbage compactor were compared to the study by Bovenzi, 2010 (Bovenzi, 2010), with frequency-weighted acceleration magnitude among the garbage compactor the reading was 0.08 in x-axis, 0.12 in y-axis and z-axis of 0.21. Only one vehicle was measured in this study. The reading of the acceleration magnitude in our study were markedly high in comparison, with the mean values for weighted acceleration for our garbage compactor truck ranged from 0.31 to 0.37 for x-axis, 0.29 to 0.32 for y-axis and 0.89 to 0.99 for z-axis respectively expressed in r.m.s. However, we measured 15 garbage compactor trucks that were available for the objective measurement of WBV.

Taxi also among the class of vehicles that being evaluated extensively in the past. However, some of the study did not revealed the exact car model hence it is mere assumption that across country the same or exact types of car being used for this purpose. For our population of taxi drivers, the models of car that commonly being utilize were the MPV (Multipurpose Vehicles) and saloon car. Reported by Funakoshi et al., 2004 (Funakoshi et al., 2004) in their study involving taxi driver the mean of z-axis weighted acceleration was 0.31 (range 0.26 to 0.34). The mean of x-axis and y-axis were both reported as 0.16 (range 0.13 to 0.18 for y-axis and 0.13 to 0.23 for x-axis). The mean readings from our vehicles classify under MPV and saloon car were comparable with this data with z-axis ranged from 0.33 to 0.39, x-axis 0.19 to 0.22 and y-axis from 0.13 to 0.18.

There is limited study available to compare on the additional evaluation which is the weighted acceleration expressed in r.m.q. Overall the readings that we gathered from multiple types of vehicles in the state of Sabah were comparable to the study conducted elsewhere. Even though not all class of vehicles were available for comparison especially the fire fighter truck, ambulance and sport utilities vehicles but in general the reading was acceptable and showing the similar pattern. The different if any being observed could be due to the other factors that influenced the acceleration magnitude. Caution also must be applied especially on how the data being collected and the exact descriptions of vehicles classification.

5.2.1.3 Daily Exposures

The mean values of the vector sum reported in (a_{ws}) and (a_{wq}) from our class of vehicles ranged from 0.4130 m/s^2 and 2.4219 m/s$^{1.75}$ respectively as the lowest reading obtained from class of ambulance and the highest reading from the garbage compactor/truck with 1.1108 m/s^2 and 6.2201 $m/s^{1.75}$ respectively. It is expected that the bigger the vehicles the higher the acceleration magnitude. Study conducted between buses and tractors revealed that the vector sum values of buses ranged from 0.24 to 0.71ms^{-2} which is lower in comparison to tractors with reported reading ranged from 0.89 to 1.41ms^{-2} (Bovenzi, 1996). However, the assumptions of light vehicles give rise to lower acceleration magnitude were contradictory in our finding. The types of vehicles classify under saloon car, MPV and SUV expected to produce low acceleration magnitude however the reading obtained were slightly higher in comparison to the ambulance. The state of vehicles gives impact on the acceleration magnitude. The types of ambulance that was available for measurement mostly manufactured less than five years as opposed to the saloon car, MPV and SUV that mostly manufactured above than five years. The acceleration magnitude dependent on year of manufacturing, one of the study compared the acceleration magnitudes measured on Fiat buses (0.46 to 0.71ms^{-2}) which is from 1.4 to three times greater than those determined on Inbus and Iveco buses (0.24 to 0.33ms^{-2}), which was revealed that the Fiat buses were constructed between years of 1968 and 1973 whereas the Inbus and Iveco were between years of 1987 to 1990 (Bovenzi, 1996).

The mean values reported in daily doses of A(8) and VDV showed that the vehicles with highest values come from the garbage compactor truck, lorry and bus. The daily dose of A(8) and VDV calculated by combining the acceleration magnitude in vector sums with the duration of exposure through hours of driving per day or per shift. This finding indicates that the duration of exposure plays major roles in determining the dose of WBV. When we combined the hours of driver being exposed to WBV, it does change the exposure level of which driver received the highest doses. In general, the fire fighter truck drivers were the group with the lowest duration of driving per day. Their services were in demand during emergency, which was very hard to predict. They still needed to check and operate the vehicles as a routine job, but they only performed those activities approximately about one to two hours per day/shift. As opposed to the bus driver, usually they required to transport passenger. Either they stop when they reached the destination or when their shifts over, which require them to drive continuous for more than four hours in a day. Thus, the need to report the dosage for WBV is an important entity. Reporting on the magnitude alone certainly underestimated the risks of the driver being exposed to WBV. Even though the acceleration magnitude produces by bus generally lower than the fire fighter truck, but they incurred more effect of vibration due to their longer duration of exposure. One of the study revealed that the back pain increases among tractor drivers with duration of exposure but it does not increase with the estimated mean magnitude vibration (Boshuizen et al., 1990). Despite expectation that the bigger the vehicles the higher the acceleration magnitude but to determine the exposure level their duration of exposures should be in cooperated.

5.2.1.4 Cumulative Exposures

The calculated WBV exposures classify under cumulative dose transformed into log form and used the interquartile range for further analysis as the data were too wide with not normally distributed. The wide variation of WBV exposures partly contributed by the calculation methods as it in cooperate duration of exposure which being the lowest as one year to the highest being 40 years. Data transformation into natural log enable to remove the tail as log rein the extreme values furthermore the interquartile range is not influenced by unusually high or low values (Sainani, 2012; Whitley & Ball, 2002). The similar methods of transforming data into logarithmic values for subsequent statistical analysis also adapted for the study addressing the dose-response relationship between hand-transmitted vibration and hand-arm vibration syndrome conducted in Malaysia (Su et al., 2013).

5.2.2 Health Risks Analysis on WBV Exposures

The health risk analysis based on the standard reference was conducted to ascertain the extend of WBV exposures among respondents.

5.2.2.1 Health Guidance Caution Zone

The difference observed between health risks analysis based on HGCZ as proposed by ISO 2631-1: 1997 and the EAV and ELV by European Directive 2002 is the limit values. Both opted to report on A(8) and VDV however the limit for European Directive 2002 is slightly higher whereby for A(8) the EAV taken as 0.5 m/s^2 as opposed in lower boundaries in HGCZ is 0.45 m/s^2 and for the ELV the values is 1.15 m/s^2 however the upper boundaries for HGCZ is 0.9 m/s^2 respectively. Similarly, the EAV expressed in VDV is 9.1 $m/s^{1.75}$ whereas the lower boundaries for HGCZ is 8.5 $m/s^{1.75}$ and the ELV is 21.0 $m/s^{1.75}$ and upper boundaries for HGCZ is 17.0 $m/s^{1.75}$. For prevention, option to use the lower limit seems to avoid under estimation furthermore the usage for HGCZ also not limited for the predominant axis alone as vector sum values can be utilized. Hence for the risks analysis the assessment using the HGCZ were adapted for comparison.

Based on individual exposure about half of the drivers fall within or above the HGCZ when reported using the A(8) and unfortunately dominated with reading exceeded the caution zone when reported using the VDV. Many other reports found the similar finding as their A(8) or VDV monitoring were above the International Organization for Standardization and European Directive recommendation (Johnson et al., 2015; Kim et al., 2015; Lewis & Johnson, 2012; Marin et al., 2016; Börje Rehn et al., 2005).

The similar pattern was also observed for risks analysis according to exposures on types of vehicles operated. Study conducted in India using the heavy earth moving machineries showed almost similar finding as higher percentage of the reading fall within or above the caution zone (Mandal & Sishodiya, 2012)

The selection of which methods being used either the A(8) or VDV gives a huge impact on our finding. Caution was taken and both methods of evaluation were reported in our study as the basic evaluation alone might not sufficient in condition of high crest factors, occasional shocks and transient vibration (ISO, 1997). Clearly shown in the results that if reading were only reported in A(8) the possibility of underestimating the degree of severity faced by the drivers. The additional methods (reading reported in VDV) were more suitable to utilize as per the opinion of the researcher. The VDV parameter is cumulative measure which is more sensitive to impulse exposure (Kim et al., 2015), the condition of the compromise state of road surfaces in Sabah produced frequent occasional shocks, where it can be appreciated when reported using the weighted acceleration in r.m.q. It was demonstrated more severe form of exposure faced among our drivers, using additional method, reported in daily doses in VDV. Monitoring using the VDV tended to give results which fall within or above the health caution zone as recommended by the ISO 2631-1: 1997 as opposed to the A(8) which tend to demonstrate reading which fall below the health caution zone. The VDV parameter calculated using the maximum or vector sums values gave a better predictions of LBP outcome over times than using the A(8) parameter calculated based on maximum and vector sums values respectively (Bovenzi, 2010). Both methods were used and were evaluated accordingly in this study for comparison. The additional methods produced more severe form of observation as most values seems to give higher likelihood of the drivers for the occurrence of health risks.

The data of the vector sum (a_{ws} and a_{wq}) values were determined as the acceleration magnitude for further utilization in the calculation of the dose exposure. Even though the z-axis were the dominant acceleration form our monitoring, but the calculation of health impact should not merely dependent on the peak acceleration as predictor because the contribution of each axis must be taken into consideration. Quoting from study by Futatsuka et al., 1998 (Futatsuka et al., 1998) referring to the previous ISO 2631-1(1985), if two or three vectorial components of a multi axis vibration have similar magnitude when the a_x, and a_y components a multiplied by 1.4, the effect on comfort and performance of the combined motion can be greater than any of the single components, hence the three values are combined to give the amount of the vector sum. If calculation of dose depending on the individual axis, the values generated might not be the true exposure that able to draw the conclusion of the health impact of WBV risks toward the drivers group. Study conducted by Rozali et al., 2009 (Rozali et al., 2009) reported the mean estimated vibration dose value (eVDV) for eight hour daily exposure at z-axis was 19.86 ± 4.72 $m/s^{1.75}$ in tracked armoured vehicles showed the highest estimation whereas the calculation of (eVDV) based on the sum of all axes for eight-hour daily exposure was 21.26 ± SD 4.71 $m/s^{1.75}$. It is demonstrated here that utilization of the dominant z-axis for calculation of daily dose of VDV produces slightly lower in comparison to utilization of the vector sum values. Another study reported a substantial difference in risk prediction between the predominant z-axis and vector sum WBV exposures (Kim et al., 2015). Their results using single axis A(8) WBV exposures were acceptable based on the ISO and EU standards (0.5 m/s^2); however the vector sum WBV exposures were above action limits. Utilization of predominant axis might underestimate the exposure as supported by finding of a study conducted by Johnson et al., 2015 reported that in all trucks, the predominant axis A(8) and VDV WBV exposures were below ISO and European Union (EU) action limits, however all vector sum exposures were above action limit (Johnson et al., 2015). Their finding able to clearly distinguish that if the peak values of dominant axis was utilized to calculate the A(8) and VDV the reading tended to be below the recommendation. The values of the vector sum also did not vary, as one of the study proven that the values are equivalent when the automated residential solid waste vehicles performed the task of collection and driving in comparison to the values that differ from collection and driving when reported as an individual axis as observed (Paschold, 2015).

5.3 Dose Response Relationship between WBV and LBP of Respondents

In the final model of the logistic regression, the finding was used as quantitatively to described on the dose response between WBV exposures and symptoms of LBP among respondents.

5.3.1 Daily exposure

Daily exposure measures that was reported in our study consisted of lna_{ws}, $lna_{wq,}$ lnA(8) and lnVDV. There were no significant associations for trend were found in all four measures of daily exposure in regard to occurrence of LBP past twelve months, past four weeks and post driving. Our findings were consistent with those reported by (Tiemessen et al., 2008) and in disagreement with finding from study conducted by (Bovenzi, 2009). As mention earlier in our study the calculation of the daily dose A(8) and VDV based on the vector sum values, however the studies as reference calculate their A(8) and VDV using both vector sums and dominant axis (Bovenzi, 2009; Tiemessen et al., 2008). We did not proceed to calculate the dominant or maximum axis as we followed the proposal that believed the impact was greater when using the vector sum values for multiple axes. It is supported by finding by (Bovenzi, 2009) they proposed thorough their finding that poor prediction were obtained with A(8) calculated using the maximum axis which is the currently preferred measure of daily WBV exposure in European countries.

There are no studies available for comparison of the occurrence of pain past four weeks, however we did not able to establish statistical significant result for the daily exposure measures.

The significant finding for the association of trend between daily driving time and driving related low back pain at quartile two (OR=1.81, 95% CI 0.97 TO 3.36), at quartile three (OR=2.31 ,95% CI 1.29 to 4.12) and at quartile four (OR=2.38 ,95% CI 1.16 to 4.90) reported by (Tiemessen et al., 2008), however we did not able to established such finding in the occurrence of LBP post driving in our study population.

Another issues that was addressed in reporting on the daily measures is the selection of which methods to adapt either the A(8) or the VDV. (Bovenzi, 2009) reported the test for trend and the pattern of the proportional ORs showed that VDV tended to give better predictions for LBP outcome than A(8) for both measures derived from the highest axis ($VDV_{max\ VS}$ $A(8)_{max}$) and measures calculated for summation over axes (VDV_{sum} vs $A(8)_{sum}$). Conflicting from the conclusion drawn by (Kim et al., 2015) reporting that their results indicate that the vertical exposure may have greater association with LBP outcomes, and based on the differences observed that the A(8) exposure may have stronger link to LBP than the impulsive VDV measures.

In our study both A(8) and VDV were obtained and calculated based on vector sum values. The results from our study did not showed any significant different between the two measures of daily doses to confer such finding. We did not able to obtain a significant finding over this method. The daily dosages seem weaker as predictor of the dose response effect in our result in comparison to the cumulative dosages. The lack of association between the currently recommended measures of daily vibration exposure, A(8) or VDV with the LBP outcomes may partly be explained by the fact that the drivers in the lower reference group were also exposed to WBV (Tiemessen et al., 2008).

5.3.2 Cumulative exposure

They were seven measures of cumulative WBV exposure evaluated for the association of the occurrence of LBP in our current study. The cumulative dosages indicated as the relative importance of the frequency-weighted acceleration a_w and the total exposure of duration T depends on the value of m [$\sum(a_w)^m T$] (Bovenzi, 2009). Assigning the a_w value of 1 to m give equals importance to the vibration magnitude a_w to the exposure duration T. With m = 0 the dose takes no account of vibration magnitude. Doses with m = 0, 1, 2 and 4 were computed for each driver. Thus the 0 order indicate only the total hours of exposure for the entire employment period reported as ln(T), the first order $\ln(a_w)T$, second order $\ln(a_w)^2T$ and the fourth order $\ln(a_w)^4T$. The acceleration magnitudes a_w were both reported in weighted acceleration in vector sum either in r.m.s (a_{ws}) or r.m.q (a_{wq}).

Tiemessen et al., 2008 reported one significant associations found between the various cumulative dose measures and twelve-month low back pain (Tiemessen et al., 2008). This association was found among the drivers in quartile three for dose two (total hours of exposure) with OR of 2.06, 95% CI 1.10 to 3.86. The total hours of exposure expressed as lnT in our current study did not have any significant result. However, we found the significant association at twelve months LBP at quartile two for $\ln(a_{ws})^2T$ (OR = 2.822, 95% CI 1.038 to 7.668) and quartile two for $\ln(a_{wq})^2T$ (OR = 2.981, 95% CI 1.096 to 8.104). Both doses were equivalent to dose four and dose seven respectively from the study conducted by (Tiemessen et al., 2008) however their results were not significant.

Tiemessen et al., 2008 reported a significant associations for trend in total years of exposure, total hours of exposure, ($a_{ws}T$), $(a_{ws})^2T$, ($a_{wq}T$) and $(a_{wq})^2T$ regressed towards driving related LBP (Tiemessen et al., 2008). However, in our study the significant association for occurrence of LBP post driving only being observed in quartile two with $\ln(a_{ws})T$ (OR= 4.208, 95% CI 1.442 to 12.277).

We also found significant trend for occurrence of LBP past four weeks at quartile two with $\ln(a_{ws})T$, $\ln(a_{ws})^2T$, $\ln(a_{wq})T$, $\ln(a_{wq})^2T$. However, we did not find other study utilize the occurrence of pain assessed past four weeks. More statistical significant results were established for pain past four weeks as results of reduced effect on reporting bias. Shorter duration ensured the drivers to remember the occurrence of pain more accurate in comparison to those symptoms that occurred past twelve months. For the assessment of pain in relation to driving as evaluated in LBP post driving, some degree of uncertainties may have occurred upon reporting the information.

In cumulative dosages calculation, selection of acceleration magnitude in r.m.s and r.m.q dose gives different effect. As reported by (Bovenzi, 2009) measure of vibration exposure derived from exposure duration (daily or lifetime) and r.m.q acceleration magnitude (VDV, $\sum [a_{wqi}{}^{m}t_i]$) were better predictors of LBP outcomes over time than measures of vibration exposure including r.m.s acceleration (A(8), $\sum [a_{wsi}{}^{m}t_i]$). In our study both methods of r.m.s and r.m.q equally comparable as we were able to establish statistical significant results using both methods. More significant finding using the cumulative instead of daily dose calculation, indicate that in our current study the cumulative were more sensitive as tools to predict the occurrence of LBP among drivers.

We also can observe that the first and second order of the dose calculation seems more sensitive to predict the occurrence of LBP. The contribution of acceleration magnitude and duration of exposure have equal contribution in that sense.

In general, the pattern of the odd for developing low back pain were observed to increase from quartile one (Q1) as reference points with lowest vibration dosage to quartile two (Q2), then subsequently reducing form quartile three (Q3) to quartile four (Q4) as the highest vibration dosages. The higher the dosages it appears to dissolve the association. This indicate that the odds for having LBP being the lowest for those drivers who exposed to higher dose at Q4 relative to those who exposed at lower dose at Q2 and Q3. Given the cross-sectional nature of the study, this could reflect reverse causation or in other words LBP could have resulted in some drivers reducing their work hours or changing job, resulting in higher occurrence of LBP among drivers who exposed to lower doses compared to those exposed at higher doses.

In the dose response relationship, in principal it should follow the pattern of increasing doses should increase the odds for development for LBP. In some circumstances as observed in our finding, we did not able to generate the dose effect according to expectation especially at higher dosage in Q4. There are possibilities can be drawn to explain the phenomena. The healthy worker effect observed as main contributor to dissolve the dose effect relationship. A study conducted among tractor drivers in Netherland, proposed that the tractor drivers who had left the company after short exposure had a high prevalence of pain or stiffness in the back which indicates significant health based selection (Boshuizen et al., 1990). Workers with severe back trouble may have stopped working on tractors and therefore have stopped accumulating vibration dose or driving years. Another study reported similar impact where they presumed that subject with radicular symptoms have a higher probability of leaving their job that leads to differential represent a selection of individuals with better constitution (Schwarze et al., 1998). Another component of healthy worker effect that can disrupt the dose effect pattern were the rate of pre-existing spinal disorders is highest in the group of lower exposure to vibration, hence possibility of selection of the fittest at the very beginning of the employment (Schwarze et al., 1998), furthermore it also proposed that professional groups are often used as an indicator of exposure vibration but in actual profession is biased by the healthy worker effect and by selective survival (Schwarze et al., 1998). Another point was the implicit assumption made using this design that damage by vibration once present will continue to cause complaints however, when repair mechanism or pain reducing – adaptation exists, the effect of vibration will be underestimated in this design and the observed dose response relation will be distorted (Boshuizen et al., 1990).

Other issues that need attention studying the dose response were the fact that in certain circumstances the WBV dosages calculated were below the limits, but the occurrence of LBP still reported among drivers group. A study reported in their finding indicated that among bus drivers with low back symptoms occurred at WBV exposure levels that were lower than the health based exposure limits proposed by the International Standard ISO 2631-1 (Bovenzi & Zadini, 1992). We can observe the different between limit values between the International Standard ISO 2631-1 and the European Vibration Directive. In the ISO 2631-1 (ISO, 1997) the standard suggested to follow the Health Guidance Caution Zone (HGCZ) which consists of lower and upper boundary values to define the probability of health risks based on magnitude of the vibration exposure. The upper and lower boundaries of the eight hours HGCZ for frequency-weighted in r.m.s accelerations A(8) are 0.9 m/s^2 and 0.45 m/s^2 and for the frequency weighted in r.m.q accelerations equivalent vibration dose values total (VDV) are 17 $m/s^{1.75}$ and 8.5 $m/s^{1.75}$ respectively. The values presented as action and limit values were comparatively lower following the European Vibration Directive (Directive 2002/44/EC). Thus, selection on which standard to adapt for comparison does influence the finding. We also noticed that most standard attempt to reevaluate their values and introducing new methods of assessing and determine the risks. The most recent standard by ISO 2631-5, 2004 developed the daily equivalent static compression dose (S_{ed}) and a risk factor (R factor) values. These methods able to determine the risk of adverse health impact on the lumbar spine when exposed to WBV with multiple shocks. However the ISO 2631-5, 2004 has not been validated at the population level (Killen & Eger, 2016).

Special attention also needed to address when comparing the results as the definition used to describe low LBP may varies. The outcome measures of LBP in our study only taking into account the time of occurrence prior to data collection. Other measures of defining LBP such as severity (chronic vs acute, pain intensity and disability) were not included in our current study. A study conducted by Bovenzi proposed that the pattern of exposure-response relationship were more evident for the outcomes high pain intensity or disability in the lower back than the binary response of twelve-month LBP (Bovenzi, 2009). Upon assessing the pain intensity and disability most of our participants were not able to give definitive answer. They were not able to recall the exact description both the intensity and disability caused by LBP. Decisions were made to omit those variables for further assessment of LBP from our study.

5.4 Additional Findings

5.4.1 LBP and Associated Risks Factors

5.4.1.1 Socio-demographic Characteristics

Only the educational attainment showed significant association with LBP at four weeks and post driving. The educational level identified as one of the determinant of LBP in the past whereby more prevalent among lower education. On the contrary our findings were in oppose to the common belief. Several studies showed that low educational attainment (primary school or less) resulted in LBP with odd ratio ranged from 1.39 to 2.54 (Burdorf & Sorock, 1997). On the other hand, there are studies that not able to demonstrate any association between LBP and education (Bovenzi, 1996, 2010; Bovenzi et al., 2006b). Apart from that, (Zadro et al., 2016) reported that only women with either general secondary or university education were less likely to experience or developed LBP but educational attainment did not affect the risk of LBP in men. They further indicate that gender is an important moderator of the relationship between educational attainment and low back pain (Zadro et al., 2016).

The reverse finding from our study may influences by the fact that those achieved tertiary education have different expectation on the types of occupation that they should embark. The general observation by the researcher during face to face interview, most of the drivers with higher education were expecting that they could get job compatible with their level of education. As reported by Durkheim (1956) quoted by (Brown, 2003) education system were believed to have two key roles. The socialization of the young into society including their future adult roles and selection into the occupational structure based on individual achievement.

In this scenario, they are proportions of our driver who achieved higher education yet has to take up the job based on their lower secondary school certificate. This identified as educational mismatches indicated by comparing the acquired level and field of education with the level and field of education considered most appropriate for the job (Allen & van der Velden, 2001). Through interviewed they admitted attempting to apply for a post which is equivalent to their educational level but did not manage to secure any decent job. Hence they accepted the job opportunity, (Robst, 2007) explained that in such condition worker accept a job for which they are overeducated to receive on job training to enhance future job prospects. However, the pitfalls for these educational mismatches imply skill mismatches which in turn have an effect on productivity and wages (Allen & van der Velden, 2001). Worker who mismatches earn less than adequately matched worker with the same amount of schooling (Robst, 2007).

We can see the pattern in our study that the drivers without low back pain at 12 months earned slightly more with mean of RM 1941.61(1023.75) than the drivers with low back pain mean monthly income of RM 1786.89 (722.83). Even though this finding was not statistically significant, we can generally assume that income does give slight impact. Nearly all the drivers with higher educational level cite their un-satisfaction for ended up being a driver as the income did not match their financial desire. In order to gained more salary, they have to accept unfavorable working conditions such as doing extra hours. As an example, the log truck drivers in New Zealand have to continue to work for 70 hour per weeks in order to achieved satisfactory income or else they have to struggle financially when there are less working hours on offer (Mackie, 2008).

This indicates that association between higher education and low back pain in our study might be due to the impact of emotional burden lead to involvement of psychosocial stressors. We postulate that drivers who attained higher education prone to had stress due to combination of many factors. Not only they have to struggle to meet their financial need, they also have to deal with the pressure from own desire and family expectation to get job with better prospect. Pressure may also be felt due to low self-esteem for not able to achieve own goal or dreams in comparison to their friend who attained similar level of education. They also have to sacrifice more hours working and less time spend with their family or for leisure. They were significant associations between low back pain and psychosocial factors including work family-imbalance (OR 1.27, 1.15-1.41) and job insecurity (OR 1.44, 1.24-1.67) (Yang, Haldeman, Lu, & Baker, 2016).

On the other hand, we also believed that drivers with higher education were more aware of the risks involved in their work environment and more concern about their health. Since the participation were based on voluntary basis, we believed that the educated driver more willingly to take part. Furthermore for those who already had episode of low back pain they would want to be identify to get better diagnosis and treatment. (Olson et al., 2011) demonstrated a significantly greater improvement with non-operative treatment for patients with lumbar disk herniation and higher educational attainment. We believed that the educated drivers with LBP get involved in our study as driven by their motivation to improve on their low back symptoms. Thus, indirectly their participation could be the medium for them to get consultation on dealing with their symptoms and way to prevent it from occurring in the future. In oppose to those with lower education, the prognosis of patients with chronic low back pain less favorable among this group (Costa et al., 2009). Hence, we anticipate that the lower educated not as much as attracted to participate. However, we should put extra caution when interpreting the results as we noticed the wide confident interval. These results could be affected due to our small sample size.

Increasing age was commonly linked with the occurrence of low back pain even among general population. As people age, they generally become less physically flexible, diminished posture and balance which may affect work or their risk of injury (Mackie, 2008). Study in the past found that increased prevalence of LBP associate with increasing age among professional drivers (Bovenzi, 1996) furthermore those within age of 36 to 40 years had OR ranged from 2.84 to 2.85 for development of LBP at 12 months (Bovenzi, 2009). However, finding were not consistent as another study by the same author found that association between increased age and LBP were not significant (Bovenzi, 2010).

Others reported a reverse association, whereby in their finding the drivers in the low back pain group were significantly younger than the drivers in the non-low back pain group with mean age of 45.0 (9.5) and 47.0 (10.0) respectively (Alperovitch-Najenson et al., 2010). In our current study, it was noticed to have similar occurrence where for those drivers who did not experienced pain at 12 months were older with mean age of 40.87 (8.89) in comparison to those who had pain with mean age of 38.94 (9.36). However, our results were not significant. We proposed that this pattern was contributed by practising good habit while driving among those older and experienced workers. It is supported by (Knox et al., 2014) where the adjusted IRRs for the less than 20-year and more than 40-year age groups, compared with the 30 to 39 years age group were 1.24 (1.15 to 1.36) and 1.23 (1.10 to 1.38) respectively. Service member who is less than 20-year and more than 40-year age group had the highest incidence rates of low back pain among motor vehicles operators. It is shown in this finding that the younger and the older group of drivers were among the most affected with occurrence of low back pain. The young driver seems to have lack of experienced and the older they are the contribution of spine degenerative changes could superimpose the occurrence of low back pain. Thus, the contribution of age as risks factor were undeniable even though we did not establish significant finding.

The involvement of gender different as a risk for the occurrence of low back pain has been documented in previous study. (Knox et al., 2014) reported that the female motor vehicles operators, compared with males from the military service members had a significantly increased adjusted incidence rate ratio (IRR) for low back pain of 1.45 (1.39-1.52). However, we did not able to elicit this finding as we did not have participation from female drivers.

The marital status, showed that being married does significantly decreased adjusted IRR for low back pain of 0.87 (0.84-0.91) (Knox et al., 2014) but finding as in opposed from another study that found being married increased the odds by 1.96 (1.05-3.62) (Tiemessen et al., 2008). We did not able to establish such finding as in agreement with finding by (Bovenzi, 2010). The effect could be diluted due to the number of participants who are single were very much less in our study.

The impact of different racial distribution for the development of low back pain among our drivers did not showed any significant result which is consistent with finding by (Knox et al., 2014).

5.4.1.2 Lifestyles Characteristics

The lifestyles behaviour characteristics able to establish association of LBP at twelve months among non-alcoholic and LBP at post driving among smoker.

In our finding smoking does increases the odds for development of LBP among participants but the significant results only being observed for LBP at post driving. The association between habit of smoking and LBP has been proven by other researchers in the past (Frymoyer et al., 1983; Goldberg, Scott, & Mayo, 2000; Shiri, Karppinen, Leino-Arjas, Solovieva, & Viikari-Juntura, 2010; Tiemessen et al., 2008) with reported odd ratio about 1.5 after adjustment for various individual and work related risks factors (Burdorf & Sorock, 1997). However some also report that there were no significant relations between LBP with habit of smoking (Bovenzi, 1996, 2010; Bovenzi et al., 2006b).

There are many hypotheses that associate the habit of smoking and the occurrence of LBP, even though the exact mechanisms are not proven (Gallais & Griffin, 2006). Smoking induced intervertebral disc degeneration (IDD) as a result of both reduced PG synthesis and increased degradation of a key disc extracellular matrix protein aggrecan. Cleavage of aggrecan IGD is extremely detrimental as this result in the loss of the entire glycosaminoglycan-attachment region of aggrecan, which is vital for attracting water necessary to counteract compressive forces (Wang et al., 2012). Another explanation is that smoking increase chronic coughing which put more pressure on the intervertebral disc and influences disc prolapse and sciatica (Gallais & Griffin, 2006). Smoking also believed to change in the disc nutrition and reduces bone mineral content making the disc more vulnerable to micro fracture (Gallais & Griffin, 2006).

The smoking habits among drivers are undeniable facts (Kaleta, Polanska, & Jegier, 2007), indicated in their finding that low levels of education, lack of recreational physical activity and medium/heavy physical work were the predictors of smoking. The typical predictor for smoker was matched with the descriptions for being a driver, furthermore it is common to see that drivers smoke while driving. Even though we cannot prove on this observation smoking while driving help to make them arouse especially for the long journey. The urge to smoke while driving also may induced by boredom because they position in a confined space inside the cabin. The assessment of LBP at post driving, were to explore the chronology of symptoms that directly related with car driving, thus association of significant finding only occurred at this point.

In our study, we demonstrated the impact of consuming alcohol reduces the odds for development of low back pain at twelve months with statistical significant results among our drivers. Our findings were in reverse as compare to the finding reported by (Ferreira, Pinheiro, Machado, & Ferreira, 2013). Other studies did not find any association between drinking habit and LBP (Bovenzi, 2010; Tiemessen et al., 2008) supported by the systematic review by (Leboeuf-Yde, 2004) concluded the same finding but add on the that the well-designed specific-alcohol-back pain-centred studies are lacking.

Evaluation of the habit of consuming alcohol in our study only gathered through face to face interviewed. Hence the answers were totally dependent on the degree of sincerity by the respondents. We strongly believed that, some drivers could rather not report on their habit because of feeling guilty for being labelled as non-compliance to certain teaching and requirement. Some just in denial for their status of being alcoholism as taking alcohol is prohibited against the law while operating a vehicle. Driving under the influence of alcohol is prohibited according to the Law of Malaysia Act 333 (Road Transport Act 1987) found in section 44, any person who, when driving a motor vehicle on a road or other public place (a) is under the influence of intoxicating liquor or drug, to such an extent as to be incapable of having proper control of the vehicle; or (b) has so much alcohol in his body that the proportion of it in his breath, blood or urine exceeds the prescribed limit, and causes the death of or injury to any person shall be guilty of an offence and shall, on conviction, be punished with imprisonment for a term of not less than three years and not more than ten years and to a fine of not less than eight thousand ringgit and not more than twenty thousand ringgit. A person convicted under this section shall be disqualified from holding or obtaining a driving licence for a period of not less than five years from the date of the conviction and, in the case of a second or subsequent conviction, be disqualified for a period of ten years from the date of the conviction. The driver seems very secretive to share such information as worried of the impact if their status is exposed. The penalty of disqualification of their driving licences upon convicted to drive under the influence of alcohol could impact on termination of their employment as drivers. We believed that more number of drivers consumed alcohol but did not admit on their status.

On the other hand, most of our drivers can be classified under social drinker. The activity of drinking session with circle of friends, can act as medium of socialization hence become part of their way to relieve stress. Studies of the relationship between alcohol and stress suggest that drinking can reduce stress in certain people and under certain circumstances (Sayette, 1999). The role of the alcohol consumption in this group of drivers seems to act indirectly, hence the impact of alcohol consumption with protective effect have to be taken with great caution.

The impact of active engagement in physical activity showed that it lower the risks for LBP (Alperovitch-Najenson et al., 2010; Bovenzi, 2009, 2010). However studies conducted by (Bovenzi, 1996; Bovenzi et al., 2006b) proved that no significant relation observed between LBP and regular sport activity. We observed in our participants, that physical activity protective for the development of LBP but our finding were not significant.

5.4.1.3 Personal and Health Related Characteristics

In this section, we able to demonstrate the association between presences of musculoskeletal pain at other body region with occurrence of low back pain among our driver at all three points of low back pain assessment. Our finding indicates that occurrence of musculoskeletal pain at other bodily region increases the risks of having LBP.

It is long being observed that the presence of musculoskeletal disorders did not occurred in isolation. The study to estimate the burden of musculoskeletal disorders in the community by (Urwin et al., 1998) in their results showed that majority of subjects who reported pain had pain in more than one site. It is likely that a person who had pain at low back is more susceptible to developed musculoskeletal pain at other body region. Furthermore, the occurrence of work related musculoskeletal disorders other than low back also shared similar risks factors. The most commonly reported biomechanical risk factors with at least reasonable evidence for causing work related musculoskeletal disorders include excessive repetition, awkward postures, and heavy lifting (Da Costa & Vieira, 2010). Another study of critical review of the epidemiologic literature by (Putz-Anderson, Bernard, & Burt, 1997) identified a number of specific physical exposures strongly associated with specific musculoskeletal disorders when exposures are intense, prolonged, and particularly when workers are exposed to several risk factors simultaneously. The occurrence of musculoskeletal disorders in this group of drivers indicates the physical stressor while driving affected different region of the body, hence induce pain simultaneously.

The musculoskeletal disorders other than lower back that mostly reported by our drivers were in their shoulder, knee and neck region which we believed associate while handling the vehicles using the manual gear transmission. The vehicles involved in our study were dominated with manual transmission. In manual gear transmission drivers need to use more of their upper and lower limbs while manipulating gear to change their speed hence affecting more on their shoulder, knee and neck.

We were not able to demonstrate any significant association for height, weight, body mass index and presence of other chronic diseases among our drivers. However, many circumstances in the past associate the impact of people with higher BMI prone to developed LBP (Björck-van Dijken, Fjellman-Wiklund, & Hildingsson, 2008; Mozafari et al., 2014). However other studies prove that BMI was inversely related to the duration of LBP and pain intensity (Bovenzi, 2010).

As explained in the descriptive part the driver in our current study observed to be more on the overweight and obese categories with majority did not performed adequate exercise. The trend of more population shifting towards overweight and obese was influence by urbanization. The developed nation always linked with access of fast food subsequently predisposed the populations to gained weight resulted from their dietary intake couple with practicing sedentary lifestyles. Indeed the obesity epidemic is a normal population response to the dramatic reduction in the demand for physical activity and the major changes in the food supply of countries (James., 2008). Malaysia in general and Sabah to be more specific also affected with these global changes. Furthermore, there is sufficient global evidence that professional drivers are less active than in the general population (Taylor & Dorn, 2006). Drivers also reported to had fewer serving of fruits and vegetables and greater consumption of fast food meals (Rose & Wojcik, 2015). Thus, it is not surprising to see increasing trend of obesity among drivers. Even though we did not able to elicit significant finding on the relationship of higher BMI for the development of low back pain, but the trend of obesity among our drivers with comorbid disorders such as diabetes and hypertension warrant attention.

5.4.1.4 Occupational Details Characteristics

In our current study, the occupational risks identified with significant finding were the adapted posture while driving for low back pain at four weeks, involvement in part time job for low back pain at twelve months and four weeks and types of working schedule for low back pain at four weeks and post driving.

Study in the past associate the development of LBP among drivers with involvement in awkward posture while operating their vehicles (Bovenzi et al., 2006b; Burdorf & Sorock, 1997) with OR ranged from 1.90 to 2.29 (Bovenzi, 1996). The awkward postures that commonly associate with low back pain were the posture bending and twisting. The adaptation of frequent bending and twisting posture involved in a very brief period but still reported with OR ranged from 1.45 to 2.13 (Chen et al., 2005; Ramond-Roquin et al., 2015; Tiemessen et al., 2008) for development of LBP. On top of that uncomfortable seat and uncomfortable back support identified to worsen the impact of ergonomic factors (Alperovitch-Najenson et al., 2010).The impact of the seated vibration exposure associated with awkward postures can affect the spine by mechanical overloading and excessive muscular fatigue, resulting in an increased susceptibility of injury to the spine (Bovenzi, 1996).

In our finding, the adaptation of torso against backrest predispose them for the development of LBP. In principal, the adaptation of this posture should be the most ideal as it provide back support while driving. We did not able to elicit the true impact of ergonomic involvement in our current study could influence by limited time of observation of posture adapted by our drivers. The monitoring of the posture was conducted at the same time of the measurement of whole body vibration which lasted approximately about 20-30 minutes. The observation for the adapted posture also conducted while the driver performed their tasks driving on the road, as such we believed that during this work process it did not entirely captured the changing of the body movement. The drivers also believed to display good habits or manner when they were being observed. Study by (Okunribido et al., 2007b) performed their posture assessment via observation however they conducted the process following the driver's service route in a completed trip – to and from lasted approximately around 1 hour 21 minutes and 1 hour 44 minutes. The time taken for observation in our study was very minimal comparatively. Furthermore, we did not apply systematic methods on assessing the posture as compared to the study by (Hoy et al., 2005) which conducted their postural observation via more systematic methods using the Ovako Working Posture Analysis System (OWAS) and Rapid Upper Limb Assessment (RULA). We believed due to the limited assessment of the postural engagement thus produce the contradictory finding.

In our study, those drivers following the shifts or other job schedule reported with less number with symptoms of low back pain. No specific study found to associate the type of working schedule to the occurrence of LBP. However, studies in the past associate long term shift work (been exposed to shift schedules for longer than 10 years) to increase the risk of arteriosclerosis observed among professional bus drivers in Taiwan compared to those who worked regular hours and followed the shift schedule for less than 10 years (short term shift drivers) (Chen et al., 2010). The impact of shift schedules lead to insufficient sleep (Chen et al., 2010) and rotating shift patterns and inflexible running times served as stressors for bus drivers (Tse et al., 2006).

As opposed we found that the shift works were more favourable to give positive impact in comparison to those working following the officer hours for our outcome measures of LBP. We presumed that working according to office hours predisposed them to drive during peak hours hence exposed to massive traffic congestion. Indeed increased road traffic (Alperovitch-Najenson et al., 2010; Tse et al., 2006) and increasingly tight running schedules becoming the growing threat of the well-being that add to the burden felt by bus drivers (Tse et al., 2006). Apart from that, caught in traffic congestion leads to more time spend driving, directly increased the exposure towards WBV. On top of that, drivers mainly engaged into inflexible working hours. Those followed the office hours schedule may not necessarily means fixed from 8am to 5pm. At certain circumstances, their service may needed out from their normal working hours. These conditions surely add on their existing stress related to work. If moved to another department their work schedule may also change as needed. Data were taken as cross-sectional studies, hence variation of the types of the work schedule participated by driver throughout their employment were not captured entirely. We strongly believed that the true impact of this parameter were not captured thus needs extra caution during interpretation. The involvement of types of job schedule also contradictory as both end following shift or office hours contributed to the negative impact.

The involvement of part time job increases the risks for development of LBP among our participants. There are no specific studies for comparison of those assessing the involvement of part time job in the past in relation to LBP. However, in principal drivers performed part time job indicate longer duration of working hours per day/shift. Working more hours than officially planned increased the risk of LBP with OR of 1.38 (Ramond-Roquin et al., 2015) involvement of irregular duty time OR of 3.0 and short resting time OR of 2.14 (Miyamoto et al., 2000). Regardless of types of part time job taken either driving or non-driving related, it acts as stressor among drivers. Indeed psychosocial stressing factors were identified as risks for development of LBP (Alperovitch-Najenson et al., 2010).

The involvement of number of working hours as main factors were undeniable as sensitive predictor for the development of LBP among drivers (Andrusaitis et al., 2006; Mozafari et al., 2014; Noda et al., 2015) especially those involved in long driving time in a day with odds ratio of 2.0 (Miyamoto et al., 2000) and those involved in driving exceeded four hours/day (Chen et al., 2005).

However, we did not able to establish the direct involvement of duration of exposure at work for the occurrence of LBP. If we compared the LBP group and the non-LBP group form our study in term duration of employment, duration of driving per day/shift (hours) and duration of driving per week (hours) we did not able to establish significant different however the group of non-LBP drivers tend to have longer exposure. However, if we compared using the accumulated mileage per day (km) and mileage per week (km) the driver with LBP group tended to accumulate higher mileage. The data obtained through interviews are highly vulnerable for error in reporting either the driver under or over reporting on their true exposures. As reported by (McCallig et al., 2010) exposure time reported in interview were higher than those observed but more reliable than those self-reported in the questionnaire. We proposed that bias in reporting the true exposure might influence our inability to generate significant association.

Another common occupational risk related for development of low back pain was the involvement of material manual handling. Positive association between back disorders and performing task of lifting or carrying loads were reported by (Burdorf & Sorock, 1997) in the review paper with OR reported of 1.95(1.31-2.91) for impact of lifting at work (Tiemessen et al., 2008) . The finding from our study revealed that those performed material manual handling carrying weight above 10kg (occasionally and often) had odds of 1.103 and 1.280 respectively but finding were not statistically significant. The tasks of performing material manual handling in our study population were not uniform. Some of them need to perform material manual handling as part of their routine especially the fire fighter and ambulance drivers but for the rest, they hardly involved in this tasks.

In principal for the involvement of risks related to work, we can conclude that the interaction between key job stressor combined with mediator or moderators to induce the occurrence of the outcome measure which in our case the LBP. This pathway illustrated by (Tse et al., 2006). In case of the occupation as drivers, they exposed to multiple job stressor such as physical environment (cabin ergonomic, traffic congestion), job design (time pressure, shifts pattern, rest breaks, social isolation) and organisational issues (reduced driver decision-making authority) and the mediators or moderators (gender, personality, social support) thus induced the occurrence of ill effect that can be divided in physical, psychological, behavioural and organisational issues.

The identified work-related risks factor that increases the occurrence of LBP among drivers in our study can be explained by their interaction among each other either directly or indirectly causing LBP using the proposed linkage as illustrated in **Figure 5.1**. The occurrence of LBP indeed contributed by many factors and their role can act as predisposing, initiating and aggravating or synergize the impact. It is believed that factors were worked in combination.

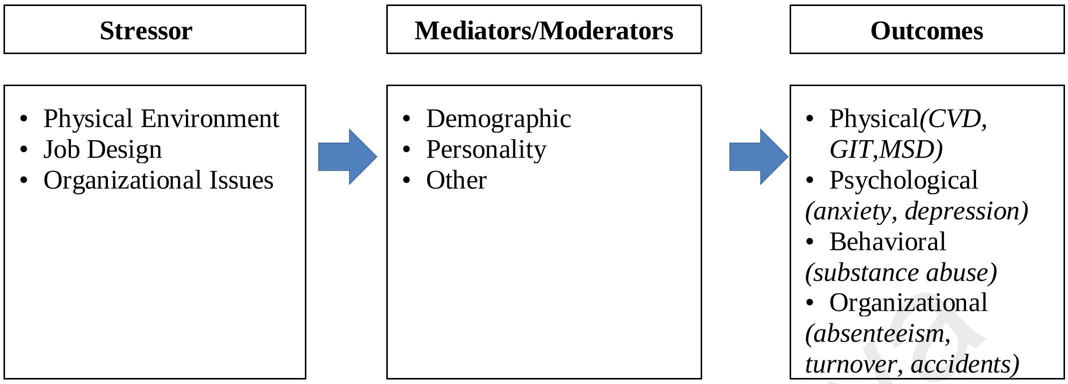

Figure 5.1: Key Job Stressor, mediating/moderating variables and outcomes of occupational stress

The main concern of our study was to evaluate the dose response effect for the subjective measurement whole body vibration and low back pain. However, we put extra caution in evaluating the common risks factors for development of low back pain as this variable can become the confounder for our results. They were many influence namely the physical, individual and psychosocial factor that associate the increased number of LBP (Gallais & Griffin, 2006) however due to time constrain the risk factors were not investigated thoroughly, especially the involvement of the psychosocial stressor. They were many circumstances in our study that the risks identified act indirectly namely the interaction of educational level, work schedule, involvement in part time job and habit of consuming alcohol. All this factor believed to give impact to add or reduce the emotional burden that contributed as psychosocial stressor.

The impacts of psychosocial stressor were undeniable among the known risks for development of LBP among drivers. The exact mechanisms underlying the association between work related psychosocial stressing factors and LBP is still uncertain. The major hypotheses include direct neurogenic effects of psychological demand on muscle tension and the ensuing biomechanical strain and stress related endocrine effect on musculoskeletal function. The psychological stress also contributes to increased tone in musculature, consequently causing increased mechanical strain on spinal structure. It also produces fatigue that could predispose drivers to traumatic injury.

5.4.1.5 Assessment of risks factor according to occurrence of LBP

The finding of significant association between the risks factor evaluated influenced by the occurrence of LBP at different time points. Only the association of other musculoskeletal pain persistently produce the significant results at all three points of LBP assessment. We believed that the occurrence of pain at other body region were sharing the common risks factor for the development of LBP in our current drivers hence the impact were being observed at all three points of assessment.

The involvements of part time job occurred at twelve months and four weeks, the education and type of work schedule at four weeks and post driving. For the impact of alcohol, smoking and adapted posture significant finding occurred at one points which was at twelve months, post driving and four weeks respectively. The impact of smoking were more prominent for the assessment of post driving as we believed drivers usually smoke concurrently while they were driving as induced by the confined spaces inside their cabin and to make them arouse on the long journey. The involvement of part time job, education, work schedule and alcohol were associated indirectly as a causative hence it did not occur consistently throughout the three points of assessment for the low back pain.

For the posture adapted the occurrence of significant results at one point of assessment could influenced by poor assessment and quantification of the risks hence affecting the outcome.

5.5 Limitations of study

The present study used cross sectional design in which the assessment of the WBV and the symptoms of LBP were conducted simultaneously. This limits the prediction and evidence to conclude the temporal relationship between the exposures and the outcome measures. On the other hand, drivers that exposed to WBV may have different susceptibility that might influence the occurrence of LBP; their susceptibility could influence by many other factors that might not related to their exposures toward WBV. Apart from that cross-sectional design may inherits potential recall bias. As the data for duration of exposures and symptoms of LBP were collected via face to face interview, participants prone to report inaccurate information. For example, overestimation for duration of exposure may lead to occurrence of dose response at a lower level.

The findings of this study may not be generalized to all types of driver's due to convenient sampling method applied for the selection of companies. For this study, most of the participations come from government statuary bodies. Even with the limited number of participation from private company, this study managed to get data from different categories of vehicles (i.e. heavy-medium-light vehicles). Random sampling method for the selection of companies was not possible because not all companies willing to fully cooperate especially during the collection of WBV data.

The estimated sample size of this study was 282 drivers. Nevertheless, only 155 drivers were recruited which achieved more than half of the target. However, the unmet sample size might compromise the power of this study to detect the true effect.

The selection of participants may introduce bias due to voluntarily participations and HWE. Although the participants were not monetary compensated, the voluntarily participations might attract certain group especially among those health-conscious individuals. The HWE could be manifested in this study as the participants involved only those who were currently employed. This suggests the "selection of the fittest" ignoring the unfit drivers (i.e. changed or quit job) which may have diminished the possibilities to detect associations between WBV and occurrence of LBP.

The estimated acceleration of WBV in this study which was taken at one point of assessment might not be the true representative of the entire exposures. Over the years drivers may accumulate variation of WBV exposures due to many factors such as changing of vehicles, condition of vehicles, road surface, etc.

The transformation of WBV data into logarithmic values need to be performed for further analysis due to the skewed data and wide range of dose exposures. Hence, we need to interpret the data with extra cautions. Similar methods were used in previous study by Su et al., 2013 (Su et al., 2013). However, since the vibration dose categories are directly divided by its quartiles values, so the values in non-logarithmic should be in correspondence to produce the dose response relationship that being observed in our results.

5.6 Strengths of study

Despite all the limitations that discuss thoroughly, this study has its own strengths. Our study can be considered as one of the few studies conducted in our local set up to studying of impact of WBV in depths. We put extra effort to calculate not only the daily measures but the cumulative measures using basic and additional evaluation methods. In our study, the measurements of WBV were mandatory requirements to all drivers with their current vehicles in used. As opposed to previous studies that only performed the measurement on the selected number of representative drivers. Data for the WBV exposure were taken during actual field measurement, thus the measurement data were deems to be specific for every individual. The drivers were required to take their usual route and three points of measurement were taken during the initiation phase, middle and towards the end of the journey. These steps taken to ensure the most accurate data that mimic their true exposure during their daily working hours or shifts.

We attempted to overcome certain problems faced during the implementation of our study, such as extending our data collection periods to get at least more than half of the intended sample size. Some mechanism also introduces such as the “working diary” for the drivers to get better estimation on their true exposure of driving duration per working day/shift. During the data collection, only one researcher involved for the face to face interview and WBV measurement. Indirectly this reduces the interviewer bias. We also provide image showing the exact location of the low back region to make sure that the drivers clearly understand the anatomical location.

Drivers participated in our study given a token of appreciation in a form of a t-shirt, which have a clear message written “Love Your Spine” at the back. The simple message like that serves to remind them to take care of their spine to prevent occurrence of LBP. During the face to face interview the researcher also tries her best to educate drivers regarding their risks and tips on preventing the occurrence of LBP in the future. The meeting session with the higher management of the companies also create opportunities to increase awareness among the employee on their roles for the safety and welfare among their worker.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The finding of this study able to demonstrate that there is present of evidence to show the indication of dose response pattern. The results generated prove that the cumulative vibration dose exposure provides good prediction of development of LBP over time in comparison to daily vibration dose exposure. The occurrence of LBP at four weeks prior to data collection also deems to reveal more of the statistical significant results in comparison to pain recorded at 12 months prior and post driving. The occurrence of low back pain at four weeks reduce the recall bias hence drivers can remember better of their incident in comparison of pain experienced past 12 months prior. Whereas for symptoms of pain at post driving, the drivers undetermined of the exact occurrence.

The study of association of risks factor for development of low back pain among drivers in Sabah revealed risks that also documented in other studies elsewhere. Below are the lists of the risks factors identified with significant statistical results.

1. Presence of other musculoskeletal complaints other than low back region
2. Involvement in part time job
3. Smoking

Some of the risks identified even though it produced significant results but need caution during interpretation. We believed that the impact were not directly but act as triggering factors.

1. Higher educational attainment increases the risks for development of low back pain.
2. Protective effect of alcohol intake for development of low back pain.
3. Working schedule following shifts reduce the occurrence of LBP among drivers.
4. Protective effect of torso straight while driving for development of LBP.

The descriptive part of the monitoring of the WBV magnitude among different types of vehicles involved, reveal that the Garbage compactor/truck reported with highest magnitude of vibration (expressed in a_{ws} and a_{wq}) and daily dose exposure (expressed in A(8) and VDV). The WBV assessment using the daily exposure level reported to have more than half of drivers identified with no or minimal risks when expressed in A(8) whereas when reporting using the VDV the assessment showed that reading were dominated with drivers imposed to have likelihood to have health risks involvement based on the HCGZ stated in ISO 2631-1: 1997.

6.2 Recommendations

6.2.1 Future Research

To address the limitations encountered in studying the impacts of WBV, we suggest adopting the longitudinal study design for future research. The adoption of this approach allows for the examination of different cohorts of worker over a period of time to determine whether their pains start before or after they join the like of work (Szeto & Lam, 2007). It certainly gives advantages as data are collected prospectively, hence reducing the recall bias or error in reporting. The exposure time can be assessed more accurately, and the occurrence of health symptoms can be reported precisely. The measurement of WBV can be conducted in several occasions to see the changes caused by the work environment (road surfaces), and the vehicle type operated by the drivers. The time taken for the monitoring can be extended to the entire driving time in a day/shifts. Moreover, the assessment of the symptoms of LBP can be performed in a series of follow up. The specific clinical examination and/or imaging modalities should be established for more accurate diagnosis. On the other hand, future studies should put special attention to follow up on individuals who change job or leave the workforce for all reasons (Laura Punnett, 1996) to ascertain the involvement of HWE.

To increase the generalizability of the impact, future research should extend the sample recruitment to other states in Malaysia. The engagement of higher authorities and enforcement bodies should be one of the strategies to encourage participations from various departments, including the private sectors, so that sampling does not depend on convenience alone. Random sampling at the individual level may also be implemented to avoid selection bias among the drivers.

The impacts of WBV among female worker were warranted to be investigated in the future. Through observation that types of work that dominated by male in the past were anticipated by female nowadays. The provision of gender represent modifier of the effect of whole body vibration exposure on the human spine were not provided (Bovenzi, 1996) as a practical consequence of the shortage of information on female workers exposed to WBV hence the guidelines and exposure limits recommended by current standards and regulations for WBV are applicable only to male workers.

Adverse health impact of WBV not only confined to musculoskeletal disorders, especially the occurrence of LBP but it involved other systems. Attempt should include exploring more on the other systems to establish health impact preceded by exposure toward WBV. Furthermore, the lack of surveillance data creates major obstacles because it perpetuates disparities among working-class populations and limits the planning and implementation of effective intervention (Apostolopoulos et al., 2010). Studying the other impact of WBV needed a base line data and lacking in surveillance system among this occupational group thus makes it difficult for further evaluation on the association. Exploration to apply more systematic assessment especially on the occupational related risks such as the postural load and MMH needed, as its ensure appropriate scoring to quantify the exposure towards the specify risks.

6.2.2 Public Health Practice

The major finding from our study proved that the drivers participated in this study were exposed to higher level of WBV. The values within and exceeded the HCGZ indicated potential and likelihood of health risks as recommended in the ISO 2631-1:1997. The next step should be taken is to ensure if the enforcement were exercised to implement the recommendation to reduce the exposure among our drivers group. The employer and employee need to understand their roles and function.

In this context, it is more important to prevent the occurrence of LBP and aiming to reduce the impact of the risks which is specific for this group of professional drivers. The occupational risks factor for LBP were among the modifiable risks, hence we believed that we can act in this area.

In Malaysia, the Department of Occupational Safety and Health Ministry of Human Resource Malaysia produce the Guidelines on Occupational Vibration, applicable for both Hand Arm Vibration and WBV. The guidelines intended to increase the awareness of employers as well as employee to the effect of vibration to human body and provide guidance on how to avoid or prevent the risks of vibration related discomfort and damage to human body. The usage of the guideline in accordance to the requirement of the Section 15(1) and 15(2) (a) & (b) of the Occupational Safety and Health Act 1994 (Act 154). The limit values for the WBV recommended using the "Threshold Limit Values (TLV)" stated in the guidelines. The guideline provides a numerical value for vibration acceleration in the longitudinal a_z and transverse a_x and a_y in a separate table to define the TLV in terms of r.m.s value pure sinusoidal single frequency vibration or r.m.s value in one third octave band for distributed vibration. The TLV values were given based on different exposure duration and different frequency (Hz). The values given in tables were in accordance to the ISO 2631-1:1985. The upgraded version of ISO 2631-1: 1997 included the reading expressed in r.m.q as this parameter able to predict worse outcome comparatively. As for the researcher opinions, the construction of the TLV values based on the weighted acceleration in r.m.s or the basic evaluation might be a limited option and not sufficient as per requirement of the ISO 2631-1:1997.

However, as being observed, the enforcement and application of the guideline need to be strengthen. Moreover, the guideline in Malaysia may need to revise and to consider adaptation to include the calculation of the TLV expressed in weighted acceleration in r.m.q for a better prediction of the risks analysis for WBV among those exposed.

Apart from strengthening the existing guidelines as LBP prevention strategies effort must be exercise as well in the enforcement area especially monitoring on the working hours. Involvement in doing part time jobs significantly associate as a risks factor in this study thus regulations should play in part to standardize the recommended working hours especially among drivers. Smoking also identified to have positive association with LBP among drivers therefore promotion on healthy lifestyles specially to combat on this bad habit should be prioritize. Other area that could be explore as well is the encouragement on activities such as types of exercise that able to strengthen joint and muscles relaxation. Symptoms of LBP among our drives coincide with presence of MSD from other body regions that might suggest muscle tension and other joints disorder when performing their tasks. One of the example is the progressive muscle relaxation (PMR) technique that commonly used for eliciting the relaxation response and relieving muscular tension. It involves sequentially relaxing various muscle groups, often starting at the head and moving down the body to the feet. Participants may tense a muscle before relaxing it (for example, clenching the jaw and then releasing it) or simply bring their attention to a muscle group and intentionally relax it. The technique believed to convey health benefits in three ways i.e. manipulation on autonomic responses, increase or activates the production of opiates and promoting optimal immune function.

REFERENCES

Allen, J., & van der Velden, R. (2001). Educational mismatches versus skill mismatches: Effects on wages, job satisfaction, and on-the-job search. *Oxford Economic Papers*, *53*(3), 434–452. https://doi.org/10.1093/oep/53.3.434

Alperovitch-Najenson, D., Santo, Y., Masharawi, Y., Katz-Leurer, M., Ushvaev, D., & Kalichman, L. (2010). Low Back Pain among Professional Bus Drivers : Ergonomic and Occupational-Psychosocial Risk Factors Low Back Pain among Professional Bus Drivers : Ergonomic and Occupational-Psychosocial Risk Factors. *IMAJ*, *12*, 2–7.

Andersson, G. B. (1999). Epidemiological features of chronic low-back pain. *The Lancet*, *354*(9178), 581–5. https://doi.org/10.1016/S0140-6736(99)01312-4

Andrusaitis, S. F., Oliveira, R. P., & Barros Filho, T. E. P. (2006). Study of the prevalence and risk factors for low back pain in truck drivers in the state of São Paulo, Brazil. *Clinics (Sao Paulo, Brazil)*, *61*(6), 503–510.

Apostolopoulos, Y., Sönmez, S., Shattell, M. M., & Belzer, M. (2010). Worksite-Induced Morbidities Among Truck Drivers in the United States. *AAOHN Journal*, *58*(7), 285–296. https://doi.org/10.3928/08910162-20100625-01

Ayari, H., Thomas, M., Doré, S., & Serrus, O. (2009). Evaluation of lumbar vertebra injury risk to the seated human body when exposed to vertical vibration. *Journal of Sound and Vibration*, *321*(1–2), 454–470. https://doi.org/10.1016/j.jsv.2008.09.046

Ayari, H., Thomas, M., Doré, S., Taiar, R., & Dron, J. P. (2009). Predicting the Adverse Health Effects To Long Term Whole-Body Vibration Exposure. *Spine*, (January), 1–19.

Aziz, S. A. A., Nuawi, M. Z., & Mohd Nor, M. J. (2014). Predicting whole-body vibration (WBV) exposure of Malaysian Army three-tonne truck drivers using Integrated Kurtosis-Based Algorithm for Z-Notch Filter Technique 3D (I-kaz 3D). *International Journal of Industrial Ergonomics*, *52*, 59–68. https://doi.org/10.1016/j.ergon.2015.08.008

Bartley, M., & Owen, C. (1996). Relation between socioeconomic status, employment, and health during economic change, 1973-93. *BMJ (Clinical Research Ed.)*, *313*(7055), 445–9. https://doi.org/10.1136/bmj.313.7055.445

Battié, M. C., Videman, T., Gibbons, L. E., Manninen, H., Gill, K., Pope, M., & Kaprio, J. (2002). Occupational driving and lumbar disc degeneration : a case- control study. *The Lancet*, *360*, 1369–1374.

Bazrgari, B., Shirazi-Adl, A., & Kasra, M. (2008). Seated whole body vibrations with high-magnitude accelerations-relative roles of inertia and muscle forces. *Journal of Biomechanics*, *41*(12), 2639–2646. https://doi.org/10.1016/j.jbiomech.2008.06.026

Begum, N. N., Ahsan, G. U., & Nazmul A. Khan. (2012). Prevalence of low back pain and associated risk factors among professional car drivers in Dhaka city, Bangladesh. *South East Asia Journal of Public Health*, *2*(1), 189–197.

Björck-van Dijken, C., Fjellman-Wiklund, A., & Hildingsson, C. (2008). Low back pain, lifestyle factors and physical activity: A population-based study. *Journal of Rehabilitation Medicine*, *40*(10), 864–869. https://doi.org/10.2340/16501977-0273

Boshuizen, H. C., Bongers, P. M., & Hulshof, C. T. J. (1990). Self-reported back pain in tractor drivers exposed to whole-body vibration. *International Archives of Occupational and Environmental Health*, *62*(2), 109–115. https://doi.org/10.1007/BF00383586

Bovenzi, M. (1996). Low back pain disorders and exposure to whole-body vibration in the workplace. *Seminars in Perinatology*, *20*(1), 38–53. https://doi.org/10.1016/S0146-0005(96)80056-5

Bovenzi, M. (2006). *Longitudinal epidemiological survey in Italy of drivers exposed to whole-body vibration*. *Risks of Occupational Vibration Exposures*.

Bovenzi, M. (2009). Metrics of whole-body vibration and exposure-response relationship for low back pain in professional drivers: a prospective cohort study. *International Archives of Occupational and Environmental Health*, *82*(7), 893–917. https://doi.org/10.1007/s00420-008-0376-3

Bovenzi, M. (2010). A Longitudinal Study of Low Back Pain and Daily Vibration Exposure in Professional Drivers. *Industrial Health*, *48*(November), 584–595. https://doi.org/10.2486/indhealth.MSWBVI-02

Bovenzi, M., & Betta, A. (1994). Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. *Applied Ergonomics*, *25*(4), 231–241. https://doi.org/10.1016/0003-6870(94)90004-3

Bovenzi, M., & Hulshof, C. T. . (1999a). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986-1997). *Int.Arch.Occup.Environ.Health*, *72*(0340–0131 SB–IM), 351–365. https://doi.org/90720351.420 [pii]

Bovenzi, M., & Hulshof, C. T. . (1999b). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986-1997). *International Archives of Occupational and Environmental Health*, *72*(6), 351–365.

Bovenzi, M., Rui, F., Negro, C., D’Agostin, F., Angotzi, G., Bianchi, S., … Stacchini, N. (2006a). An epidemiological study of low back pain in professional drivers. *Journal of Sound and Vibration*, *298*(3), 514–539. https://doi.org/10.1016/j.jsv.2006.06.001

Bovenzi, M., Rui, F., Negro, C., D’Agostin, F., Angotzi, G., Bianchi, S., … Stacchini, N. (2006b). An epidemiological study of low back pain in professional drivers. *Journal of Sound and Vibration*, *298*(3), 514–539. https://doi.org/10.1016/j.jsv.2006.06.001

Bovenzi, M., & Zadini, A. (1992). Self-reported low back symptoms in Urban bus drivers exposed to whole-body vibration. *Spine*, *17*(9), 1048–1059. https://doi.org/10.1097/00007632-199209000-00007

Brown, P. (2003). *The Oppurtunity Trap: Educational and Employment in Global Economy*. *Time*.

Burdorf, A., & Sorock, G. (1997). Positive and negative evidence of risk factors for back disorders. *Scandinavian Journal of Work, Environment & Health*, *23*(4), 243–56. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9322815

Burgess, M., & Foster, G. (2012). *Implementation and Effectiveness of the European Directive Relating To Vibration in the Workplace*.

Chen, C. C., Shiu, L. J., Li, Y. L., Tung, K. Y., Chan, K. Y., Yeh, C. J., … Wong, R. H. (2010). Shift Work and Arteriosclerosis Risk in Professional Bus Drivers. *Annals of Epidemiology*, *20*(1), 60–66. https://doi.org/10.1016/j.annepidem.2009.07.093

Chen, J.-C., Chan, W. P., Katz, J. N., Chang, W. P., & Christiani, D. C. (2004a). Occupational and personal factors associated with acquired lumbar spondylolisthesis of urban taxi drivers. *Occupational and Environmental Medicine*, 992–998.

Chen, J.-C., Chan, W. P., Katz, J. N., Chang, W. P., & Christiani, D. C. (2004b). Occupational and personal factors associated with acquired lumbar spondylolisthesis of urban taxi drivers. *Occupational and Environmental Medicine*, *61*(12), 992–998. https://doi.org/10.1136/oem.2003.011775

Chen, J.-C., Chang, W.-R., Chang, W., & Christiani, D. (2005). Occupational factors associated with low back pain in urban taxi drivers. *Occupational Medicine (Oxford, England)*, *55*(7), 535–540. https://doi.org/10.1093/occmed/kqi125

Chen, J.-C., Chang, W.-R., Shih, T.-S., Chen, C.-J., Chang, W. P., Dennerlein, J. T., … Christiani, D. C. (2004). Using "Exposure Prediction Rules" for Exposure Assessment An Example on Whole Body Vibration in Taxi Drivers. *Epidemiology*, *15*(3).

Chen, J. C., Chang, W. R., Shih, T. S., Chen, C. J., Chang, W. P., Dennerlein, J. T., … Christiani, D. C. (2003). Predictor of whole-body vibration levels among urban taxi drivers. *Ergonomics*, *46*(11), 1075–1090.

Chen, R., & Seaton, A. (1996). The influence of study characteristics on the healthy worker effect : a multiple regression analysis. *Occup Med (Lond)*, *46*(5), 345–350. https://doi.org/10.1093/occmed/46.5.345

Costa, L. d. C. M., Maher, C. G., McAuley, J. H., Hancock, M. J., Herbert, R. D., Refshauge, K. M., & Henschke, N. (2009). Prognosis for patients with chronic low back pain: inception cohort study. *BMJ*, *339*(oct06 2), b3829–b3829. https://doi.org/10.1136/bmj.b3829

Cronin, J. B., Oliver, M., & Mcnair, P. J. (2004). Muscle stiffness and injury effects of whole body vibration. *Physical Therapy in Sport*, *5*, 68–74. https://doi.org/10.1016/j.ptsp.2004.01.004

Da Costa, B. R., & Vieira, E. R. (2010). Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *American Journal of Industrial Medicine*, *53*(3), 285–323. https://doi.org/10.1002/ajim.20750

Dawson, A. P., Steele, E. J., Hodges, P. W., & Stewart, S. (2009). Development and Test-Retest Reliability of an Extended Version of the Nordic Musculoskeletal Questionnaire (NMQ-E): A Screening Instrument for Musculoskeletal Pain.

Journal of Pain, *10*(5), 517–526. https://doi.org/10.1016/j.jpain.2008.11.008

Department of Occupational Safety and Health Ministry of Human Resources Malaysia. (2003). *Guidelines on Occupational Vibration*. https://doi.org/983-2014-24-7

Diamond, S., & Borenstein, D. (2006). Chronic low back pain in a working-age adult. *Best Practice and Research: Clinical Rheumatology*, *20*(4), 707–720. https://doi.org/10.1016/j.berh.2006.04.002

Dickinson, C. E., Campion, K., Foster, A. F., Newman, S. J., O'Rouke, A. M. T., & Thomas, P. G. (1992). Questionnaire development: an examination of the Nordic Musculoskeletal Questionnaire. *Applied Ergonomics*, *23*(3).

Donati, P., Schust, M., Reinert, D., Flaspoler, E., Szopa, J., Starck, J., … Cockburn, W. (2005). Application of Vibration Directive in 6 Europen Countries. *Hand-Arm Vibartion*, (July 2005), 635–644.

Donati, P., Schust, M., Szopa, J., Starck, J., Iglesias, E. G., Senovilla, L. P., … Op d Beeck, R. (2008). *Workplace exposure to vibration in Europe: an expert review*.

Dundurs, J. (2001). Whole-body Vibration at Work of Urban Traffic Drivers. *Environmental Health*, (4), 4–6.

Economic Planning Unit. (2015). *Logistics and trade facilitation masterplan (2015-2020)*. *Ministry of Transport Malaysia*. Retrieved from http://www.mot.gov.my/en/Penerbitan Rasmi/Executive Summary Logistics and Trade Facilitation Masterplan.pdf

Eger, T., Stevenson, J., Boileau, P. E., & Salmoni, A. (2008). Predictions of health risks associated with the operation of load-haul-dump mining vehicles: Part 1-Analysis of whole-body vibration exposure using ISO 2631-1 and ISO-2631-5 standards. *International Journal of Industrial Ergonomics*, *38*(9–10), 726–738. https://doi.org/10.1016/j.ergon.2007.08.012

El-Khatib, A., & Guillon, F. (2001). Lumbar intradiscal pressure and whole body vibration-first results. *Clinical Biomechanics*, *16*(1), 127–134.

European Parliment and the council of European Union. (2002). *Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration)*. *Official Journal of the European Communities*.

Fadhli, M., Humairah, N., Khairul, N., Kaswandi, M., & Zunaidah, Z. (2016). Ergonomic Risk Factors and Prevalence of Low Back Pain among Bus Drivers. *Austin Journal of Musculoskeletal Disorders*, *3*(1), 1–3.

Ferguson, F., Holdsworth, L., & Rafferty, D. (2010). A national framework for supporting improvements in the physiotherapy assessment and management of low back pain: The Scottish experience. *Physiotherapy*, *96*(3), 198–205. https://doi.org/10.1016/j.physio.2010.02.001

Ferreira, P. H., Pinheiro, M. B., Machado, G. C., & Ferreira, M. L. (2013). Is alcohol intake associated with low back pain? A systematic review of observational studies. *Manual Therapy*, *18*(3), 183–190.

https://doi.org/10.1016/j.math.2012.10.007

Foster, G., & van Leeuwen, M.-J. (2007). Managing Vibration Exposure. In *The 2007 Queensland Mining Conference* (pp. 1–9).

Fritz, M., & Schäfer, K. (2011). Influence of the Posture of the Trunk on the Spine Forces during Whole-Body Vibration. *Journal of Low Frequency Noise, Vibration and Active Control*, *30*(4), 277–290. https://doi.org/10.1260/0263-0923.30.4.277

Frymoyer, J. W., Pope, M. H., Clements, J. H., Wilder, D. G., MacPherson, B., Ashikaga, T., & Vermont, B. (1983). Risk Factors in Low Back Pain. *Journal of Bone and Joint Surgery*, *65*, 213–18.

Funakoshi, M., Taoda, K., Tsujimura, H., & Nishiyama, K. (2004). Measurement of Whole-Body Vibration in Taxi Drivers. *Journal of Occupational Health*, *46*(2), 119–124. https://doi.org/10.1539/joh.46.119

Futatsuka, M., Maeda, S., Inaoka, T., Nagano, M., Shono, M., & Miyakita, T. (1998). Whole-Body Vibration and Health Effects in the Agricultural Machinery Drivers. *Industrial Health*, *36*, 127–132. https://doi.org/10.2486/indhealth.36.127

Gallais, L., & Griffin, M. J. (2006). Low back pain in car drivers: A review of studies published 1975 to 2005. *Journal of Sound and Vibration*, *298*(3), 499–513. https://doi.org/10.1016/j.jsv.2006.06.012

Goldberg, M. S., Scott, S. C., & Mayo, N. E. (2000). A review of the association between cigarette smoking and the development of nonspeciWc back pain and related outcomes. *Spine*, *25*(8), 995–1014.

Goon, S., & Bipasha, M. S. (2012). Tobacco Use Insights, 1–8. https://doi.org/10.4137/TUI.S13966.RECEIVED

Government of Alberta. (2010). *Best Practices – Vibration at the Work Site*.

Greenhalgh, S., & Salfe, J. (2009). A qualitative investigation of Red Flags for serious spinal pathology. *Physiotherapy*, *95*, 223–226.

Griffin, M. J., Howart, H. V. ., Pitts, P. M., Fischer, S., Kaulbars, U., Donati, P. M., & Bereton, P. . (2008). *Guide to good practice on Whole-Body Vibration*.

Gryllias, K., Yiakopoulos, C., Karamolegkou, S., & Antoniadis, I. (2016). Human-Body Vibration Exposure Experienced by Tram Drivers- An Evalation According to ISO Standards and European Directives. In *The 23rd International Congress on Sound and Vibration* (pp. 1–8).

Gyi, D. E., & Porter, J. M. (1998). Musculoskeletal problems and driving in police officers. *Occupational Medicine*, *48*(3), 153–160.

Hampel, G. A., & Chang, W. R. (1999). Body height change from motor vehicle vibration. *International Journal of Industrial Ergonomics*, *23*(5–6), 489–498. https://doi.org/10.1016/S0169-8141(98)00008-0

Harris, A. M., Cripton, P. A., & Teschke, K. (2012). Retrospective Assessment of Occupational Exposure to Whole Body Vibration for a Case Control Study.

Journal of Occupational and Environmental Hygiene, *9*, 371–380.

Hartvigsen, J., Bakketeig, L. S., Leboeuf-Yde, C., Engberg, M., & Lauritzen, T. (2001). The Association Between Physical Workload and Low Back Pain Clouded by the “Healthy Worker” Effect. *Spine*, *26*(16), 1788–1792. https://doi.org/10.1097/00007632-200108150-00011

Heederik, D. (2006). Micro-epidemiology of the healthy worker effect? *Occup.Environ.Med.*, *63*(2), 83. https://doi.org/10.1136/oem.2005.024307

Hosada, M., Stone, D. L., & Stone-Romero, E. F. (2003). The interactive effect of race, gender and type of job suitability ratings and selection decisions. *Journal of Applied Social Psychology*.

Hoy, D., Bain, C., Williams, G., March, L., Brooks, P., Blyth, F., … Buchbinder, R. (2012). A systematic review of the global prevalence of low back pain. *Arthritis and Rheumatism*, *64*(6), 2028–2037. https://doi.org/10.1002/art.34347

Hoy, D., Brooks, P., Blyth, F., & Buchbinder, R. (2010). The Epidemiology of low back pain. *Best Practice and Research: Clinical Rheumatology*, *24*(6), 769–781. https://doi.org/10.1016/j.berh.2010.10.002

Hoy, D., March, L., Brooks, P., Woolf, A., Blyth, F., Vos, T., & Buchbinder, R. (2010). Measuring the global burden of low back pain. *Best Practice and Research: Clinical Rheumatology*, *24*(2), 155–165. https://doi.org/10.1016/j.berh.2009.11.002

Hoy, J., Mubarak, N., Nelson, S., Sweerts De Landas, M., Magnusson, M., Okunribido, O., & Pope, M. (2005). Whole body vibration and posture as risk factors for low back pain among forklift truck drivers. *Journal of Sound and Vibration*, *284*, 933–946. https://doi.org/10.1016/j.jsv.2004.07.020

HSE. (2005a). *Control back-pain risks from whole-body vibration : Advice for employers on the Control of Vibration at Work Regulation 2005*.

HSE. (2005b). *Whole-body vibration The Control of Vibration at Work Regulations 2005 Guidance on Regulations*.

Huber, G., Skrzypiec, D. M., Klein, A., Püschel, K., & Morlock, M. M. (2010). High Cycle Fatigue Behaviour of Functional Spinal Units. *Industrial Health*, *48*, 550–556.

Hulshof, C. T. J., Van Der Laan, G., Braam, I. T. J., & Verbeek, J. H. A. M. (2002). The Fate of Mrs Robinson: Criteria for Recognition of Whole-Body Vibration Injury As an Occupational Disease. *Journal of Sound and Vibration*, *253*(1), 185–194. https://doi.org/10.1006/jsvi.2001.4255

Hulshof, C., & Veldhuijzen Van Zanten, B. (1987). Whole-body vibration and low-back pain A review of epidemiologic studies*. *Intemational Archives of Int Arch Occup Environ Health*, *59*, 205–220. https://doi.org/10.1007/BF00377733

ISO. (1997). *International Standard ISO 2631-1: Mechanical Vibration and shock-Evaluation of human exposure to whole-body vibration*. https://doi.org/10.5594/J09750

Jabatan Perangkaan Malaysia. (2015). *Laporan Tahunan 2015*.

James WP. (2008). The fundamental drivers of the obesity epidemic. *Obesity Reviews*, *9*, 6–13.

Johanning, E., Fischer, S., Christ, E., Göres, B., & Landsbergis, P. (2002). Whole-Body Vibration Exposure Study in U.S. Railroad Locomotives-An Ergonomic Risk Assessment. *AIHA Journal*, *63*, 439–446. https://doi.org/10.1080/15428110208984732

Johnson, P. W., Dennerlein, J., Ramirez, L. M., Arias, C., & Rodríguez, A. C. (2015). Assessment of continuous and impulsive whole body vibration exposures in heavy equipment mining vehicles. In *Teiennial Congress of the IEA* (pp. 1–5).

Kaewboonchoo, O., Yamamoto, H., Miyai, N., Mirbod, S. M., Morioka, I., & Miyashita, K. (1998). The standardized nordic questionnaire applied to workers exposed to hand-arm vibration. *Journal of Occupational Health*, *40*(3), 218–222. https://doi.org/10.1539/joh.40.218

Kaleta, D., Polanska, K., & Jegier, A. (2007). Smoking predictors among economically active individuals. *International Journal of Occupational Medicine & Environmental Health*, *20*(4), 357–363. https://doi.org/10.2478/v10001-007-0037-x

Killen, W., & Eger, T. (2016). *(Position Paper) Whole-Body Vibration : Overview of Standards Used to Determine Health Risks*.

Kim, J. H., Aulck, L., Hughes, M., Zigman, M., Cavallari, J., Dennerlein, J. T., & Johnson, P. W. (2015). Whole Body Vibration Exposures in Long-haul Truck Drivers. In *Human Factors and Ergonomics Society 59th Annual Meeting* (pp. 1274–1278).

Knox, J. B., Orchowski, J. R., Scher, D. L., Owens, B. D., Burks, R., & Belmont, P. J. (2014). Occupational driving as a risk factor for low back pain in active-duty military service members. *Spine Journal*, *14*(4), 592–597. https://doi.org/10.1016/j.spinee.2013.06.029

Krismer, M., & van Tulder, M. (2007). Low back pain (non-specific). *Best Practice and Research: Clinical Rheumatology*, *21*(1), 77–91. https://doi.org/10.1016/j.berh.2006.08.004

Kumar, A., Varghese, M., Mohan, D., Mahajan, P., Gulati, P., & Kale, S. (1999). Effect of Whole Body Vibration on the Low Back. *Spine*, *24*(23), 2506–2515.

Kuorinka, I., Jonsson, B., Kilbom, a, Vinterberg, H., Biering-Sørensen, F., Andersson, G., & Jørgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics*, *18*(3), 233–237. https://doi.org/10.1016/0003-6870(87)90010-X

Land Transport Authority Malaysia. (2016). *Motor vehicle population by type of vehicles*.

Leboeuf-Yde, C. (2004). Back pain - Individual and genetic factors. *Journal of Electromyography and Kinesiology*, *14*(1), 129–133.

https://doi.org/10.1016/j.jelekin.2003.09.019

Leelavathy, K. R., Raju, R., & Raj, S. G. (2013). An Empirical Investigation and Development of Model for Measuring the Perceived Low Back Pain Prevalence Level Among Drivers in India. *International Journal of Engineering Science and Technology*, *5*(04), 719–730.

Lewis, C. A., & Johnson, P. W. (2012). Whole-body vibration exposure in metropolitan bus drivers. *Occupational Medicine*, *62*(7), 519–524. https://doi.org/10.1093/occmed/kqs096

Li, W., Zhang, M., Lv, G., Han, Q., Gao, Y., Wang, Y., … Li, Z. (2015). Biomechanical response of the musculoskeletal system to whole body vibration using a seated driver model. *International Journal of Industrial Ergonomics*, *45*(August), 91–97. https://doi.org/10.1016/j.ergon.2014.12.006

Lines, J., Stiles, M., & Whyte, R. (1994). Whole body vibration during tractor driving. *Journal of Low Frequency Noise Vibration and Active Control*, *14*(2), 87–104.

Lings, S., & LeboeufYde, C. (2000). Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992-1999. *Int.Arch.Occup.Envir.Health*, *73*(5), 290–297. https://doi.org/10.1007/s004200000118

Lis, A. M., Black, K. M., Korn, H., & Nordin, M. (2007). Association between sitting and occupational LBP. *European Spine Journal*, *16*(2), 283–298. https://doi.org/10.1007/s00586-006-0143-7

Lis, A. M., Black, K. M., & Nordin, M. (2007). Association between sitting and occupational LBP. *Acao Ergonomica*, *1*(3), 73–86. https://doi.org/10.1007/s00586-006-0143-7

Luoma, K., Riihimäki, H., Luukkonen, R., Raininko, R., Viikari-Juntura, E., & Lamminen, A. (2000). Low Back Pain in Relation to Lumbar Disc Degeneration. *Spine*, *25*(4), 487–492. https://doi.org/10.1097/00007632-200002150-00016

Mackie, H. (2008). *The health and fitness of log truck drivers : An evaluation of the industry and recommendations for action*. *Log Transport Safety Council*. Retrieved from http://www.logtruck.co.nz/pdf/Driver Health and safety Main report final Feb 08.pdf

Magnusson, M. L., Pope, M. H., Hulshof, C. T. J., & Bovenzi, M. (1998). Development of a Protocol for Epidemiologal Studies of Whole-Body Vibration and Musculoskeletal Disorders of the Lower Back. *Journal of Sound and Vibration*, *215*(4), 643–651. https://doi.org/10.1006/jsvi.1998.1697

Maher, C., Underwood, M., & Buchbinder, R. (2016). Non-specific low back pain. *The Lancet*, *389*(10070), 736–747. https://doi.org/10.1016/S0140-6736(16)30970-9

Maikala, R. V., Bhambhani, Y. N., & King, S. (2006). Acute physiological responses in healthy men during whole body vibration. *Int Arch Occup Environ Health*, *79*, 103–114.

Majid, K., & Truumees, E. (2008). Epidemiology and Natural History of Low Back

Pain. *Seminars in Spine Surgery*, *20*(2), 87–92. https://doi.org/10.1053/j.semss.2008.02.003

Malaysian Investment Development Authority. (2012). *Malaysia: Investment in the services sector (Logistic Services)*.

Manchikanti, L. (2000). Epidemiology of Low Back Pain. *Pain Physician*, *3*(2), 167–192. https://doi.org/10.1161/STROKEAHA.115.009171

Mandal, B., & Sishodiya, P. K. (2012). Selection of mining equipment for use in Indian mines based on their vibration hazard potential.

Mansfield, N. J., & Marshall, J. M. (2001). Symptoms of musculoskeletal disorders in stage rally drivers and co-drivers. *Br J Sports Med*, *35*, 314–320.

Marin, L. S., Rodriguez, A., Rey, E., Piedrahita, H., Barrero, L. H., Dennerlein, J., & Johnson, P. W. (2016). Influence of Speed in Whole Body Vibration Exposure in Heavy Equipment Mining Vehicles. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 60, pp. 919–922). https://doi.org/10.1177/1541931213601211

Marjanen, Y. (2006). *Developing whole body vibration measuring and analysis methods for enabling continuous personal exposure monitoring*.

Mayton, A. G., Jobes, C. C., & Gallagher, S. (2014). Assessment of whole-body vibration exposures and influencing factors for quarry haul truck drivers and loader operators. *Int J Heavy Veh Syst*, *21*(3), 241–261. https://doi.org/10.1504/IJHVS.2014.066080.Assessment

McCallig, M., Paddan, G., Van Lente, E., Moore, K., & Coggins, M. (2010). Evaluating worker vibration exposures using self-reported and direct observation estimates of exposure duration. *Applied Ergonomics*, *42*(1), 37–45. https://doi.org/10.1016/j.apergo.2010.04.002

Mcphee, B., Foster, G., & Long, A. (2009). *A handbook on Whole Body Vibration exposure in mining*.

Ministry of Health Malaysia. (2015). *National Health & Morbidity Survey 2015*.

Miyamoto, M., Konno, S., Gembun, Y., Liu, X., Minami, K., & Ito, H. (2008). Epidemiological study of low back pain and occupational risk factors among taxi drivers. *Industrial Health*, *46*(2), 112–117. https://doi.org/10.2486/indhealth.46.112

Miyamoto, M., Shirai, Y., Nakayama, Y., Gembun, Y., & Kaneda, K. (2000). An epidemiologic study of occupational low back pain in truck drivers. *Journal of Nippon Medical School = Nippon Ika Daigaku Zasshi*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10851352

Mohebbi, I., Saadat, S., Aghassi, M., Shekari, M., Matinkhah, M., & Sehat, S. (2012). Prevalence of metabolic syndrome in iranian professional drivers: Results from a population based study of 12,138 men. *PLoS ONE*, *7*(2), 1–5. https://doi.org/10.1371/journal.pone.0031790

Mozafari, A., Vahedian, M., Mohebi, S., & Najafi, M. (2014). Work-related musculoskeletal disorders in truck drivers and official workers. *Acta Medica Iranica*, *53*(7), 432–438.

Nakashima, A. M. (2004). *The effect of vibration on human performance and health: A review of recent literature*.

Nelson, C. M., & Brereton, P. F. (2005). The European vibration directive. *Industrial Health*, *43*(3), 472–479. https://doi.org/10.2486/indhealth.43.472

Nishiyama, K., Taoda, K., & Kitahara, T. (1998). A Decade of Improvement in Whole-Body Vibration and Low Back Pain for Freight Container Tractor Drivers. *Journal of Sound and Vibration*, *215*(4), 635–642. https://doi.org/10.1006/jsvi.1998.1700

Noda, M., Malhotra, R., DeSilva, V., Sapukotana, P., DeSilva, A., Kirkorowicz, J., … Østbye, T. (2015). Occupational risk factors for low back pain among drivers of three-wheelers in Sri Lanka. *International Journal of Occupational and Environmental Health*, *21*(3), 216–224. https://doi.org/10.1179/2049396714Y.0000000071

Okunribido, O. O., Magnusson, M., & Pope, M. (2006). Delivery drivers and low back pain: A study of the exposures to posture demands, manual materials handling and whole body vibration. *International Jouranl of Industrial Ergonomics*, *36*, 265–273.

Okunribido, O. O., Magnusson, M., & Pope, M. H. (2006). Low back pain in drivers: The relative role of whole-body vibration, posture and manual materials handling. *Journal of Sound and Vibration*, *298*(3), 540–555. https://doi.org/10.1016/j.jsv.2006.06.007

Okunribido, O. O., Shimbles, S. J., Magnusson, M., & Pope, M. (2007a). City bus driving and low back pain: A study of the exposures to posture demands, manual materials handling and whole-body vibration. *Applied Ergonomics*, *38*(1), 29–38. https://doi.org/10.1016/j.apergo.2006.01.006

Okunribido, O. O., Shimbles, S. J., Magnusson, M., & Pope, M. (2007b). City bus driving and low back pain: A study of the exposures to posture demands, manual materials handling and whole-body vibration. *Applied Ergonomics*, *38*(1), 29–38. https://doi.org/10.1016/j.apergo.2006.01.006

Olson, P. R., Lurie, J. D., Frymoyer, J., Walsh, T., Zhao, W., Morgan, T. S., … Weinstein, J. N. (2011). Lumbar Disc Herniation in the Spine Patient Outcomes Research Trial. *Spine*, *36*(26), 2324–2332. https://doi.org/10.1097/BRS.0b013e31820bfb9a

Palmer, K. T., Griffin, M. J., Bendall, H., Pannett, B., & Coggon, D. (2000). Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey. *Occupational and Environmental Medicine*, *57*(4), 229–236. https://doi.org/10.1136/oem.57.4.229

Palmer, K. T., Griffin, M. J., Syddall, H. E., Pannett, B., Cooper, C., & Coggon, D. (2003). The relative importance of whole body vibration and occupational lifting as risk factors for low-back pain. *British Journal of Industrial Medicine*, *60*(10), 715–721. https://doi.org/10.1136/oem.60.10.715

Palmer, K. T., Harris, C. E., Griffin, M. J., Bennett, J., Reading, I., Sampson, M., & Coggon, D. (2008a). Case-control study of low-back pain referred for magnetic resonance imaging, with special focus on whole-body vibration. *Scandinavian Journal of Work, Environment & Health*, *34*(5), 364–373. https://doi.org/10.5271/sjweh.1282

Palmer, K. T., Harris, E. C., Griffin, M. J., Bennett, J., Reading, I., Sampson, M., & Coggon, D. (2008b). Case-Control Study of Low-Back Pain Presenting for MRI , With Special Relation To Whole-Body Vibration. *Scand.J Work Environ Health*, *34*(5), 364–373.

Pankoke, S., Hofmann, J., & Wolfel, H. P. (2001). Determination of the vibration-related spinal loads by numerical simulation. *Clinical Biomechanics*, *16*(1), 45–56.

Paschold, H. (2015). Whole-Body Vibration in Automated Residential Solid Waste Collection. *Journal of Safety Science and Technology*, *5*(December), 85–92.

Pengel, L. H. M., Herbert, R. D., Maher, C. G., & Refshauge, K. M. (2003). Acute low back pain: systematic review of its prognosis. *BMJ (Clinical Research Ed.)*, *327*(7410), 323. https://doi.org/10.1136/bmj.327.7410.323

Pope, M. H., Goh, K. L., & Magnusson, M. L. (2002). Spine Ergonomics. *Annual Review of Biomedical Engineering*, *4*(1), 49–68. https://doi.org/10.1146/annurev.bioeng.4.092101.122107

Pope, M. H., & Hansson, T. H. (1991). Vibration of the spine and Low Back Pain. *Clinical Orthopaedics and Related Research*, *279*(49–59).

Pope, M., Magnusson, M., Lundstrom, R., Hulshof, C., Verbeek, J., & Bovenzi, M. (2002). Guidelines for Whole-Body Vibration Health Surveillance. *Journal of Sound and Vibration*, *253*(1), 131–167. https://doi.org/10.1006/jsvi.2001.4253

Punnett, L. (1996). Adjusting for the healthy worker selection effect in cross-sectional studies. *International Journal of Epidemiology*, *25*(5), 1068–1076. https://doi.org/10.1093/ije/25.5.1068

Punnett, L., Pruss-Ustun, A., Nelson, D. I., Fingerhut, M. A., Leigh, J., Tak, S., & Phillips, S. (2005). Estimating the global burden of low back pain attributable to combined occupation exposure. *Amer. J. Indust. Med.*, *48*(September), 4459–4469. https://doi.org/10.1002/ajim.20232.

Putz-Anderson, V., Bernard, B., & Burt, S. (1997). *Musculoskeletal disorders and workplace factors*. *U.S. Department of Health and Human Services* (Vol. 97–141). Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Musculoskeletal+disorders+and+workplace+factors#1%5Cnhttp://www.cdc.gov/niosh/docs/97-141/pdfs/97-141.pdf

QuestTechnologies. (2008a). *VI-410 Advanced Analyzer USER MANUAL*.

QuestTechnologies. (2008b). *Whole Body Vibration Monitoring Quick Start Setup Guide*.

Raffler, N., Hermanns, I., Sayn, D., Göres, B., Ellegast, R., & Rissler, J. (2010).

Assessing combined exposures of whole-body vibration and awkward posture--further results from application of a simultaneous field measurement methodology. *Industrial Health*, *48*(5), 638–644. https://doi.org/10.2486/indhealth.MSWBVI-27

Raffler, N., Hermanns, I., Sayn, D., Göres, B., Ellegast, R., Rissler, J., & Augustin, S. (2010). Assessing Combined Exposures of Whole-body Vibration and Awkward Posture — Further Results from Application of a Simultaneous Field Measurement Methodology. *Industrial Health*, *48*, 638–644.

Ramond-Roquin, A., Bodin, J., Serazin, C., Parot-Schinkel, E., Ha, C., Richard, I., … Roquelaure, Y. (2015). Biomechanical constraints remain major risk factors for low back pain. Results from a prospective cohort study in French male employees. *The Spine Journal*, *15*(4), 559–569. https://doi.org/10.1016/j.spinee.2013.05.040

Rehn, B., Lundstrom, R., Nilsson, L., Liljelind, I., & Jarvholm, B. (2005). Variation in exposure to whole-body vibration for operators of forwarder vehicles — aspects on measurement strategies and prevention. *International Journal of Industrial Ergonomics*, *35*, 831–842. https://doi.org/10.1016/j.ergon.2005.03.001

Rehn, B., Nilsson, T., Olofsson, B., & Lundström, R. (2005). Whole-body vibration exposure and non-neutral neck postures during occupational use of all-terrain vehicles. *Annals of Occupational Hygiene*, *49*(3), 267–275. https://doi.org/10.1093/annhyg/meh077

Robst, J. (2007). Education and job match: The relatedness of college major and work. *Economics of Education Review*, *26*(4), 397–407. https://doi.org/10.1016/j.econedurev.2006.08.003

Rose, S., & Wojcik, J. (2015). The Health Habits and Physical Activity of Student Truck Drivers The Health Habits and Physical Activity of Student Truck Drivers. *The Winthrop McNair Research Bulletin*, *1*, 69–76.

Rozali, A., Rampal, K. G., Shamsul Bahri, M. T., Sherina, M. S., Shamsul Azhar, S., Khairuddin, H., & Sulaiman, A. (2009). Low back pain and association with whole body vibration among military armoured vehicle drivers in Malaysia. *Medical Journal of Malaysia*, *64*(3), 197–204.

Sainani, K. L. (2012). Dealing With Non-normal Data. *PMRJ*, *4*(12), 1001–1005. https://doi.org/10.1016/j.pmrj.2012.10.013

Salmoni, A. W., Cann, A. P., Gillin, E. K., & Eger, T. R. (2008). Case studies in whole-body vibration assessment in the transportation industry-Challenges in the field. *International Journal of Industrial Ergonomics*, *38*(9–10), 783–791. https://doi.org/10.1016/j.ergon.2007.10.002

Samuel, O. A., & Babajide, L. E. (2012). The prevalence of work-related musculoskeletal disorder among occupational taxicabs drivers in Nigeria. *Ijrras*, *11*(3), 561–567.

Sayette, M. A. (1999). Does drinking reduce stress? *Alcohol Research & Health : The Journal of the National Institute on Alcohol Abuse and Alcoholism*, *23*(4), 250–5. https://doi.org/yes

Scarlett, A. J., Price, J. S., Semple, D. A., & Styner, R. M. (2005). *Whole-body* *vibration on agricultural vehicles : evaluation of emission and estimated exposure levels. Health & Safety Executive.*

Schwarze, S., Notbohm, G., Dupuis, H., & Hartung, E. (1998). Dose–Response Relationships Between Whole-Body Vibration and Lumbar Disk Disease—a Field Study on 388 Drivers of Different Vehicles. *Journal of Sound and Vibration*, *215*(4), 613–628. https://doi.org/10.1006/jsvi.1998.1602

Seidel, H. (2005). On the Relationship between Whole-body Vibration Exposure and Spinal Health Risk. *Industrial Health*, *43*(October), 361–377. https://doi.org/10.2486/indhealth.43.361

Seidel, H., Blüthner, R., & Hinz, B. (2001). Application of finite-element models to predict forces acting on the lumbar spine during whole-body vibration. *Clinical Biomechanics (Bristol, Avon)*, *16 Suppl 1*(1), S57–S63. https://doi.org/10.1016/S0268-0033(00)00106-6

Seidel, H., Bluthner, R., Hinz, B., & M. Schust. (1998). On the Health Risk of the Lumbar Spine Due To Whole-Body Vibration — Theoretical Approach , Experimental Data and Evaluation of Whole-Body Vibration. *Journal of Sound and Vibration*, *215*, 723–741. https://doi.org/10.1006/jsvi.1998.1601

Seidel, H., Hinz, B., Hofmann, J., & Menzel, G. (2008). Intraspinal forces and health risk caused by whole-body vibration-Predictions for European drivers and different field conditions. *International Journal of Industrial Ergonomics*, *38*(9–10), 856–867. https://doi.org/10.1016/j.ergon.2007.10.007

Shah, D. (2009). Healthy worker effecf phenomenon. *Indian Journal of Occupational and Environmental Medicine*, *13*(2), 77–79.

Shemory, S. T., Pfefferle, K. J., & Gradisar, I. M. (2016). Modifiable Risk Factors in Patients With Low Back Pain. *Orthopedics*, *39*(3), e413-6. https://doi.org/10.3928/01477447-20160404-02

Shiri, R., Karppinen, J., Leino-Arjas, P., Solovieva, S., & Viikari-Juntura, E. (2010). The Association between Smoking and Low Back Pain: A Meta-analysis. *American Journal of Medicine*, *123*(1), 87.e7-87.e35. https://doi.org/10.1016/j.amjmed.2009.05.028

Siebert, U., Rothenbacher, D., Daniel, U., & Brenner, H. (2001). Demonstration of the healthy worker survivor effect in a cohort of workers in the construction industry. *Occupational and Environmental Medicine*, *58*(12), 774–779. https://doi.org/10.1136/OEM.58.12.774

Steenland, K., Deddens, J., Salvan, A., & Stayner, L. (1996). Negative bias in exposure-response trends in occupational studies: modeling the healthy workers survivor effect. *Am.J Epidemiol.*, *143*(2), 202–210. https://doi.org/10.1093/oxfordjournals.aje.a008730

Su, A., Maeda, S., Fukumoto, J., Darus, A., Hoe, V. C. W., Miyai, N., … Miyashita, K. (2013). Dose-response relationship between hand-transmitted vibration and hand-arm vibration syndrome in a tropical environment. *Occupational and Environmental Medicine*, *70*, 495–504.

Szeto, G. P. Y., & Lam, P. (2007). Work-related musculoskeletal disorders in urban bus drivers of Hong Kong. *Journal of Occupational Rehabilitation*, *17*, 181–198. https://doi.org/10.1007/s10926-007-9070-7

Tamrin, S. B. M., Yokoyama, K., Jalaludin, J., Aziz, N. A., Jemoin, N., Nordin, R., … Abdullah, M. (2007). The Association between risk factors and low back pain among commercial vehicle drivers in peninsular Malaysia: a preliminary result. *Industrial Health*, *45*(2), 268–278. https://doi.org/10.2486/indhealth.45.268

Taylor, A. H., & Dorn, L. (2006). Effects of physical inactivitiy on stress, fatigue, health and risk of at-work road traffic accidents. *Annual Review of Public Health*, *27*, 371–391.

Thamsuwan, O., Blood, R. P., Ching, R. P., Boyle, L., & Johnson, P. W. (2013). Whole body vibration exposures in bus drivers : A comparison between a high-floor coach and a low-floor city bus. *International Journal of Industrial Ergonomics*, *43*(1), 9–17. https://doi.org/10.1016/j.ergon.2012.10.003

Thygesen, L. C., Hvidtfeldt, U. A., Mikkelsen, S., & Brønnum-Hansen, H. (2011). Quantification of the healthy worker effect: a nationwide cohort study among electricians in Denmark. *BMC Public Health*, *11*(1), 571. https://doi.org/10.1186/1471-2458-11-571

Tiemessen, I. J. H., Hulshof, C. T. J., & Frings-Dresen, M. H. W. (2008). Low back pain in drivers exposed to whole body vibration: analysis of a dose-response pattern. *Occupational and Environmental Medicine*, *65*(10), 667–675. https://doi.org/10.1136/oem.2007.035147

Torén, A., Öberg, K., Lembke, B., Enlund, K., & Rask-Andersen, A. (2002). Tractor-driving hours and their relation to self-reported low-back and hip symptoms. *Applied Ergonomics*, *33*(2), 139–146. https://doi.org/10.1016/S0003-6870(01)00061-8

Tse, J. L. M., Flin, R., & Mearns, K. (2006). Bus driver well-being review: 50 years of research. *Transportation Research*, *9*(2), 89–114. https://doi.org/10.1016/j.trf.2005.10.002

Turner, L. M., & Reed, D. B. (2011). Exercise Among Commercial Truck Drivers. *AAOHN Journal*, *59*(10), 429–436. https://doi.org/10.3928/08910162-20110916-01

Urwin, M., Symmons, D., Allison, T., Brammah, T., Busby, H., Roxby, M., … Williams, G. (1998). Estimating the burden of musculoskeletal disorders in the community: the comparative prevalence of symptoms at diVerent anatomical sites, and the relation to social deprivation. *Ann Rheum Dis*, *57*, 649–655. https://doi.org/10.1136/ard.57.11.649

Videman, T., & Battié, M. C. (2012). Commentary: Back pain epidemiology - The challenge of case definition and developing new ideas. *Spine Journal*, *12*(1), 71–72. https://doi.org/10.1016/j.spinee.2011.12.007

Virtanen, I. M., Karppinen, J., Taimela, S., Ott, J., Barral, S., Kaikkonen, K., … Ala-Kokko, L. (2007). Occupational and Genetic Risk Factors Associated With Intervertebral Disc Disease. *Spine*, *10*, 1129–1134.

Waddell, G., & Burton, A. K. (2001). Occupational health guidelines for the management of low back pain at work: Evidence review. *Occupational Medicine*, *51*(2), 124–135. https://doi.org/10.1093/occmed/51.2.124

Wang, D., Nasto, L. A., Roughley, P., Leme, A. S., Houghton, A. M., Usas, A., … Vo, N. (2012). Spine degeneration in a murine model of chronic human tobacco smokers. *Osteoarthritis and Cartilage*, *20*(8), 896–905. https://doi.org/10.1016/j.joca.2012.04.010

Wang, W., Bazrgari, B., Shirazi-adl, A., Rakheja, S., & Boileau, P.-émile. (2010). Biodynamic Response and Spinal Load Estimation of Seated Body in Vibration Using Finite Element Modeling. *Industrial Health*, *48*, 557–564.

Waters, T., Genaidy, A., Viruet, H. B., & Makola, M. (2008). The impact of operating heavy equipment vehicles on low back disorders. *Ergonomics*, *51*(5), 602–636.

Wen, C. P., & Tsai, S. P. (1982). Anatomy of the healthy worker effect. A critique of summary statistics employed in occupational epidemiology. *Scandinavian Journal of Work, Environment and Health*, *8*(Suppl. 1), 48–52.

Whitley, E., & Ball, J. (2002). Statistics review 1 : Presenting and summarising data, *6*(1).

Wiersma, U. J. (1990). Gender differences in job attribute preferences: Work-home role conflict and job level as mediating variables. *Journal of Occupational Psychology*, *63*(3), 231–243. https://doi.org/10.1111/j.2044-8325.1990.tb00524.x

Wilder, D. G., & Pope, M. H. (1996). Epidemiological and aetiological aspects of low back pain in vibration environments - An update. *Clinical Biomechanics*, *11*(2), 61–73. https://doi.org/10.1016/0268-0033(95)00039-9

Winkleby, M. A., Ragland, D. R., Fisher, J. M., & Syme, S. L. (1988). Excess risk of sickness and disease in bus drivers: A review and synthesis of epidemiological studies. *International Journal of Epidemiology*, *17*(2), 255–262. https://doi.org/10.1093/ije/17.2.255

Yang, H., Haldeman, S., Lu, M.-L., & Baker, D. (2016). Low Back Pain Prevalence and Related Workplace Psychosocial Risk Factors: A Study Using Data From the 2010 National Health Interview Survey. *Journal of Manipulative and Physiological Therapeutics*, *39*(7), 459–472. https://doi.org/10.1016/j.jmpt.2016.07.004

Yoshimura, T., Nakai, K., & Tamaoki, G. (2005). Multi-body dynamics modelling of seated human body under exposure to whole-body vibration. *Industrial Health*, *43*(3), 441–447. https://doi.org/10.2486/indhealth.43.441

Zadro, J. R., Shirley, D., Pinheiro, M. B., S??nchez-Romera, J. F., P??rez-Riquelme, F., Ordo??ana, J. R., & Ferreira, P. H. (2016). Does educational attainment increase the risk of low back pain when genetics are considered? A population-based study of Spanish twins. *Spine Journal*, *17*(4), 518–530. https://doi.org/10.1016/j.spinee.2016.10.021

Zock, J. P., Heederik, D., & Doekes, G. (1998). Evaluation of chronic respiratory effects in the potato processing industry: indications of a healthy worker effect? *Occupational and Environmental Medicine*, *55*(12), 823–827.

APPENDIX A: List of Publications and Papers Presented

Type	***Title***	***Journal/Venue***	***Status***
Poster Presentation	Dose Response Realtionship Between WBV and LBP at four weeks among different types of vehicular drivers in the State of Sabah	Faculty of Medicine Research Week/ University of Malaya (24^{th} – 28^{th} March 2014)	Presented
Oral Presentation	Dose Response Realtionship Between WBV and LBP at four weeks among different types of vehicular drivers in the State of Sabah	2^{nd} Sabah Regional Public Health Conference & 11^{th} Sabah Public Health Colloquium/ Promenade Hotel Kota Kinabalu (11^{th} – 14^{th} October 2016)	Presented and awarded "Consolation Prize"