

ASSOCIATION BETWEEN WHOLE BODY VIBRATION AND LOW BACK DISORDERS IN FARMERS: A  
SYSTEMATIC REVIEW AND A PROSPECTIVE COHORT STUDY

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by

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## Abstract

### Background

Low back disorders (LBDs) are the most common musculoskeletal problem among farmers, with higher prevalence rates than in other occupations. Operators of tractors and other farm machinery such as combines and all terrain vehicles (ATV) can have considerable accumulation of exposure to whole body vibration (WBV). The causal relationship between LBDs and WBV is not fully clear; however, it may be different among farmers as their work context and exposure is unique.

### Objectives

The objectives of the two studies which form two manuscripts or chapters in this thesis were to: 1) investigate the associations between WBV and LBDs among farmers using a) systematic review (manuscript 1) and cohort studies (manuscript 2).

### Methods

*Objective 1:* Nine databases were searched using groups of terms for two concepts: ‘farming’ and ‘low back disorder’. Screening, data extraction and quality assessment was performed by two reviewers independently. The population was adult farmers or agricultural workers globally irrespective of sex. The intervention was considered to be WBV exposure, such tractor, combine and ATV use. The control was no exposure or low exposure to WBV and the outcome was low back disorders. No limits in date of publication and type of study design were applied in the literature search, and only full text, English language studies were considered.

*Objective 2:* The data source was the Saskatchewan Farm Injury Cohort Study. In 2007, baseline data were collected on accumulated yearly tractor, combine, ATV operation, as well as several

biopsychosocial covariates thought to be associated with LBDs. Follow-up data on LBDs and related symptoms were collected during 2013 (6 year follow-up) and 2014 (1-year). This resulted in two datasets for each of two cohorts: 1) the first cohort with 1,149 farm people who had been followed for six years, and 2) the second with 605 participants who had been followed for one year. Generalized estimating equation-modified Poisson regressions were performed with low back and hip symptoms as the outcome.

## **Results**

*Objective 1:* After 276 full texts screened, we found 12 articles which analyzed WBV as a risk factor for LBD. Three were case-control, 6 cross-sectional and 3 retrospective cohorts. Four studies showed no association between WBV and LBDs, 4 studies showed a positive association and for the remaining 4 studies, results were mixed depending on the exposure or the outcome measure. *Objective 2:* The adjusted model in cohort 1 found LBDs to be associated to tractor operation for 1-150 hrs/year (RR=1.23, 95%CI 1.05-1.44), 151-400 hrs/year (RR=1.32, 95%CI 1.14-1.54) and 401+ hrs/year (RR=1.34, 95%CI 1.15-1.56). In addition, tractor operation for 151-400 hrs/year (RR=1.95, 95%CI 1.45-2.62) and 401+ hrs/year (RR=1.79, 95%CI 1.32-2.45) was also found to be related to hip symptoms. Although combine operation  $\geq 61$  hrs/year and ATV operation 81+ days/year was related to LBD in the bivariate analysis in cohort 1, this association did not persist after adjustment for confounders. Due to limited power, no significant bivariate association was found between WBV and either LBDs and hip symptoms in cohort 2.

## **Conclusions**

*Objective 1:* A firm conclusion is difficult due to heterogeneity in statistical strategy, LBDs definition, type of farm commodity, and study design. Direct comparisons and synthesis were

not possible. Although retrospective cohort studies tended to show a relationship, future studies with a prospective cohort design can help clarify this association further. *Objective 2:* Although duration of tractor operation and older age showed with both LBDs and hip symptoms in farmers in cohort 1, the true prospective cohort 2 found no significant association between WBV and LBDs.

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## **Dedication**

I would like to dedicate this thesis to my cherished parents, Rev. Daniel Kojo Essien and Osofo Maame Augustina Afia Bentum who through their words of encouragement, constant prayers, and unconditional love inspired me throughout every step in my academic Journey. I also dedicate this thesis to the Essien brothers who through their motivation, counselling, and passion towards the furtherance of my education keep sustaining me as I journey along the stages of academic life.



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## **List of Abbreviations**

ATV: All Terrain Vehicles

AR: Autoregressive

BMI: Body Mass Index

CI: Confidence Interval

GEE: Generalized Estimating Equations

ISO: International Organization for Standardization

LBD: Low Back Disorder

LBP: Low Back Pain

OR: Odds Ratio

QIC: Quasi-Likelihood under the Independence Model Criterion

RR: Relative Risk

RMS: Root Mean Square

SNQ: Standardized Nordic Questionnaire

SFIC: Saskatchewan Farm Injury Cohort

VDV: Vibration Dose Value

WBV: Whole Body Vibration

RMQ: Root Mean Quad

## **Chapter 1: Introduction**

Globally, low back disorders (LBDs) are a common health problem in the general population. Not only are LBDs prevalence rates increasing, but they come with high economic burden [1]. The growing concerns of LBDs are that they often affect the working population [2], which may be attributable to work-related risk factors. Therefore, this chapter will focus on a brief description of work-related LBDs; economic burden of LBDs; prevalence of LBDs in the general population as well as in the agricultural sector; whole body vibration (WBV) as a risk factor for LBDs; WBV exposure patterns; and types of WBV measurements.

Low back disorders (LBDs) are the most common musculoskeletal problem in the workplace [3]. Work-related low back disorder is an umbrella term that covers both low back pain (LBP) and low back injuries [4]. LBDs are significant public health concern with high social and economic costs [5, 6]. In addition, LBDs can affect individuals' quality of life [7] which include physical and psychological health [8], and as well being an important cause of disability [2]. Insight into the economic burden of LBDs, prevalence of LBDs, and the growing concerns of WBV exposure in the agriculture sector is presented in the sections to come.

### **1.1 Economic burden of LBDs**

LBDs have a substantial economic impact. LBDs are associated with high costs to industry and individuals, with 37% percent of the global burden of low-back pain attributed to work and estimated “to cause 818,000 disability-adjusted life years lost annually” [9]. LBDs have been found to impose high economic cost both on organizations and countries. High economic costs

of LBDs have been observed internationally: Japan 82.14 billion yen [10], United Kingdom £ 12,300 million [11]; Australia \$9.17 billion [12] and United States \$7.4 billion [13-15] per year. An estimated 2 percent of European gross domestic product (GDP) is accounted for by the direct costs of musculoskeletal disorders each year and out of this, the cost of back pain has been estimated to exceed €12billion [16]. Health Canada estimates that musculoskeletal disorders, including back pain, cost society \$16.4 billion in combined direct (treatment and rehabilitation) and indirect (lost- productivity) costs [17].

## **1.2 Prevalence of LBDs**

LBDs are among the most common health problem faced in the world today and nearly 90% of the general global population is estimated to suffer from LBDs [18]. Work-related activities were associated with two-thirds of low back disorders cases in a study conducted in the United States [19]. The US National Safety Council reported in 1991 that back injuries were the most frequent of all disabling work injuries in the United States[20]; their statistics revealed that about 31% of all workers' compensation cases were related to back injuries [20]. In the industrial world, high prevalence of work-related LBD has been observed in United States [21], Germany, and Spain with respective prevalence of 80%, 37% and 32.9% [22]. Many of these low back disorders are associated with occupational factors and significantly increase workers' compensation costs [23]. LBDs account for approximately 16-19% of all workers' compensation claims, and about 33-41% of the total cost of all workers' compensation costs [23, 24]. In Canada, LBDs affects 85% of the working population and 80% are expected to experience LBP in their lifetime [17]. More than 107,000 claims for back strains were received by WorkSafe BC from the period 2000 to 2004 representing 25% and over of all workers' compensation claims

[25-27]. In Saskatchewan, 38% of people with low back pain reported a history of work-related low back injury [28].

### **1.3 LBDs and referred pain in the hip and lower limb**

In addition to pain in the low back region, LBDs may refer pain to the hip [29] and leg [30]. Hip dysfunction has been reported to be related to LBP “because of the anatomical proximity of the hip and lumbopelvic region” [31]. Rostocki reports that “lower back and hip pains are often experienced together, making it a common combination symptom syndrome” [32]. He further stated that “pain in the hips is sometimes related to many of the usual causes of lower back pain”, since both the hip and back work together in many functional tasks; it is common for pain that affects one area to also have direct effect on the other [32]. A study on work and health among farmers found that there is a connection between prolonged tractor driving and increased risk of back trouble (pain), as well as radiologically confirmed hip joint arthritis [33]. Similarly, Stupar et al. observed that “alleviating low back symptoms may impact on hip pain and function” [34]. Low back pain has also been found to be significantly associated with knee pain and disability [35]. Hence, it is worth investigating the hip as well as the lower limb when considering LBD, as pain could radiate from the low back to the hip and the lower limb area.

### **1.4 Agriculture: increased risk of LBDs**

LBD is the most common musculoskeletal problem experienced in the agricultural sector, where it is more common than in other industries [2]. Driscoll et al.’s worldwide study on occupationally-related LBP found the highest risk (RR=3.7) in the agricultural sector [2]. Within the agricultural industry, farmers are particularly vulnerable to developing LBDs; these may arise from their work which “frequently incorporates activities” and occupational exposures



that are “thought to be risk factors for developing low back pain” [20, 36]. Farming is a heterogeneous occupation with many kinds of commodities and production methods, so exposures can also be varied. Farming is furthermore distinct in that farms are often places of residence populated by children and elderly [37], and to a great extent rely on family labour [38]. Worker traits, behaviours, setting and organizational structure also account for the uniqueness in farming among occupations [39]. Not only does farming have more self-employed workers and long hours of working, farmers also retire at later age than most other workers [40]. Also, farmers are employed younger than in other occupations [41, 42]. The latter statement raises the issue on the importance of age at which one starts working and also for lifetime exposure, especially in a vibration-prone job setting. Dupuis and Zerlett note that “the age of the worker when first exposed to vibration at work is important as long as the growth of the spinal column is not yet complete”[43]. Clearly, agriculture is a unique milieu with a different set of risk factors and requires independent investigation.

#### **1.4.1 Prevalence of LBDs in farmers**

High prevalence of LBDs has been found in farmers. A study of risk factors for back pain among male farmers found that 31% of farmers in US reported having daily back pain for a week or more compared to 18.5% in the general working population [44]. In addition, previous studies found LBD prevalence range of 37-60% in farmers in Ireland and India [45, 46]. A study to determine the prevalence of low back pain and other musculoskeletal disorders among Kansas farmers found that the low back was the anatomical area with the highest prevalence of self-reported work-related pain (37.5%) [47]. Liu et al. found 38.4% prevalence of back pain in Chinese farmers, with it affecting work quantity and quality [48]. Findings of a study in three

provinces of Thailand demonstrated that low back pain was the most frequent musculoskeletal problem among farmers in these areas, with 56.91% reporting seven-day prevalence and 73.31% reporting twelve-month prevalence [48]. Essen et al. note 71 % of swine producers in the US reported chronic back pain [49]. Although higher prevalence of LBDs has been observed in farmers, the extent to which WBV is associated with LBDs is not clear.

#### **1.4.2 LBDs risk factors: a biopsychosocial model**

LBDs are affected by factors in many dimensions, not only physical exposures or risk factors. According to Pincus et al. “the biopsychosocial model of back pain has become a dominant model in the conceptualization of the etiology and prognosis of back pain” [50]. The three areas captured by this model are biological, psychological, and social factors [50]. Gerdle et al. also noted that both acute and chronic pain are “influenced by and interact with physical, emotional, psychological, and social factors” [51]. Pincus et al. also found “good evidence for the role of biological, psychological, and social factors in the etiology and prognosis of back pain” [50].

Macleod et al. defined psychosocial factors as “any exposure that may influence a physical health outcome through a psychological mechanism” [52]. Previous studies have found psychosocial factors such as low wage, job satisfaction, feeling stressed, depression and high job insecurity [53] and education [54-57] to be related to increased LBP. In addition, other personal characteristics such as body mass index (BMI) [58, 59], age, sex [2, 55, 60], height [61] and lifestyle factors such smoking [55, 62-64] have also been found to be related to LBP. These

reinforce the importance of accounting for these variables, as they may confound the relationship between a risk factor and LBDs.

### **1.4.3 Risk factors for LBD among farmers**

A recent systematic review of epidemiological literature published by Osborne et al. investigating risk factors for musculoskeletal disorders among farm owners and farm workers, found that the risk factors for musculoskeletal disorders among farmers are varied and may be classified in terms of work characteristics, personal characteristics, and psychosocial factors [65]. Although Osborne et al. investigated farming exposures broadly; their review did not focus on WBV exposures specifically [65]. Physical hazards which farmers are exposed to during work include: “lifting and carrying heavy loads, working with the trunk in sustained flexion and exposure to vibration from farm vehicles and power hand tools” [66, 67]. In view of these physical hazards and especially driving of agricultural tractors, Cvetanovic et al. found exposure to vibration to be especially harmful, as there could be a health risk if exposed to one hour in a day [68]. This finding highlights the importance in investigating WBV exposures specifically as a risk factor for LBDs.

### **1.5 Whole body vibration: a risk factor for LBDs**

WBV occurs when “workers sit or stand on vibrating seats or foot pedals” [69]. The vibration is then transmitted to the body part in contact with the vibration sources especially the “legs when standing and the buttocks and back when sitting” [70]. Vehicles or machinery found to produce WBV in various industries include: forklift truck, lorry, tractor, bus, and loader [71]. However, the causal relationship between WBV and LBDs is not fully clear. Results of reviews have been mixed, with some showing an association [72-75] and some not [71, 76, 77].

A systematic review commissioned by WorkSafe BC in 2001 to investigate the association between whole body vibration and low back pain concluded that there was insufficient evidence to establish that WBV was causally associated with low back pain in the workplace [78]. However, the authors added that since most of articles reviewed were based on cross-sectional studies “the ability to assess temporal relationships of exposure to WBV to the development of LBD was lacking” [78]. Likewise, Waters et al.’s review on heavy equipment vehicles and LBDs also concluded that their review could not provide definitive evidence on the causal association between WBV and LBD, and strongly suggested the deployment of prospective cohort studies to investigate this association as well as studies to investigate the biological plausibility of this association [79]. The reason for not finding an association in Water’s et al.’s review could be due to limitations of cross-sectional design as most evidence were drawn from cross-sectional studies [79]. In addition, Bovenzi et al.’s review on WBV and LBP also concluded that there is not sufficient evidence of a clear relationship between WBV and LBDs, and the authors similarly attributed the insufficient evidence to limitations of cross-sectional design [80].

### **1.5.1 WBV in agriculture**

In agriculture, the sources of WBV have been found to include “wheel-type agricultural tractors and self-propelled farm machines (e.g., combine harvesters)” [81]. Cvetanovic et al. noted that agricultural tractor drivers are exposed to various physical exposures with vibration being considered among the most harmful factors [68]. This makes farmers who operate tractors and other types of machinery generally vulnerable to whole body vibration; in part due to

“unevenness of road or soil profile” and “moving elements within the machine (vehicle)” or its attached implements [82].

### **1.5.2 Whole body vibration measurement in agriculture**

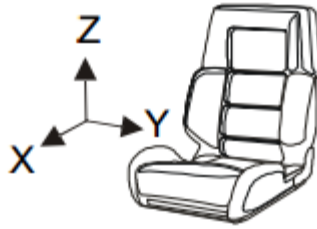
Farm machinery operators are exposed to different vibration patterns [69]. This is because of specific machinery with distinct frequencies, together with other occupational factors that influence vibration magnitude such as driving surface. Dupuis and Zerlett saw the need to account for the kind of machine or vehicle used when evaluating the effect of WBV, as vehicles and machinery “can be very different from the motion and work conditions” [43]. Factors found to influence vibration magnitude include: engine size; body weight; age of the vehicle; use of seat cushion; type of vehicle; suspension type; and nature of road surface [69, 83] .

### **1.5.3 Weighted frequency**

The occupationally safe-range for exposure to WBV is  $0.5 \text{ ms}^{-2} \text{ A}(8)$  or  $9.1 \text{ ms}^{1.75} \text{ VDV}$  [84].

These measurements can be summarized in several different ways, including power spectrum, weighted R.M.S, and vibration dose value (VDV).

Vibration exposure may be expressed in terms of its magnitude (acceleration ( $\text{m/s}^2$ )) in the time domain, and its frequency (Hertz (Hz)) [85]. This vibration exposure may be quantified in three axes namely: vertical (z), front and back (x), and lateral (y) [85, 86] (see figure 1).



**Figure 1: Axes measurement relative to the seat (X-axis; back to front, Y-axis; right to left and Z-axis; foot to head) Diagram adapted from Whole-body vibration and ergonomics tool kit research report [87].**

Since the human health effects of vibration vary depending on the frequency the operator is exposed to, frequency weighting is considered in the calculation of the exposure [85]. In addition, since the effect of WBV is dependent on the direction, the weighted frequency vibration value is also multiplied by a direction factor (x and y axes is 1.4, and the z-axis is 1.0 ) [85].

The vibration magnitude is then calculated using the formula:

$$a = \left[ (1.4a_{xw})^2 + (1.4a_{yw})^2 + (a_{zw})^2 \right]^{0.5} \quad (1)$$

Where:  $a_{xw}$ ,  $a_{yw}$ ,  $a_{zw}$  are the root-mean-square acceleration magnitudes in  $m/s^2$  for the x, y, z axes respectively [85, 88-90].

The root-mean-square (R.M.S) acceleration value captures a cumulative exposure which is adjusted to represent an 8-hour working day [84, 91].

#### 1.5.4 Vibration Dose Value (VDV)

Vibration dose value is the “time integral of the acceleration” [84, 91] and is based on a “fourth power time dependency to accumulate vibration severity over the exposure period from the shortest possible shock to a full day (8 hours) of vibration” [92].

VDV can be expressed as

$$VDV = \left\{ \int_0^T [a_w(t)]^4 dt \right\}^4 \quad (2)$$

where,  $a_w(t)$  is the instantaneous frequency-weighted acceleration [93, 94].

The difference between the VDV method and the r.m.s is that the VDV method is “more sensitive to impulsive vibration” [94], and “responds more readily to the shocks in a signal compared with r.m.s and it maintains this influence as time passes” [84, 91]. Sandover notes that the VDV is more reliable in terms of measuring health risk resulting from the presence of high acceleration events than the weighted R.M.S [95].

#### 1.5.5 Equivalent vibration magnitude and total vibration dose

Equivalent and summarized vibration measures of WBV incorporate the use of a task exposure matrix or ‘vehicle exposure matrix’ to combine self-reported time on each vehicle to develop a cumulative dose model. Boshuizen et al. term these estimated vibration magnitudes per vehicle as an “equivalent vibration magnitude” and “total vibration magnitude” [96].

The derived equivalent vibration magnitude is then calculated using the formula:

$$\text{Equivalent vibration magnitude} = \sqrt{\frac{\sum (a_i^2 t_i)}{t_i}} \quad (3)$$

where  $t_i$  = time spent on vehicle “i” and  $a_i$  = estimated vector sum of the weighted acceleration in all three directions: x, y, and z [96].

Alternatively, the total vibration dose according to Boshuizen et al.[96] is calculated based on the ISO 2631/1 time-dependence for daily exposure and is expressed as:

$$\text{Total vibration dose} = \sum_i a_i^2 t_i \quad (4)$$

These latter approaches have been applied successfully in previous studies involving agricultural tractor operators [89, 96, 97]. However, it is not clear which method is best to measure the association of WBV and low back disorders [98]. Nielson et al. note that the “frequency weighted rms-value, which is normally used to estimate the risk of the effect from WBV, is probably not optimal” [98] in predicting LBD; they argued that the use of a measure, “which is more sensitive to peak values of the vibration would probably be more correct” [98]; this seems to suggest the use of the VDV instead.

Although no single measurement summary measuring procedure is complete in describing WBV complexity, Bovenzi notes that “measures of vibration exposure derived from exposure duration (daily or lifetime) and root-mean quad (R.M.Q) acceleration magnitude (e.g., VDV) were better predictors of LBD outcomes over time than measures of vibration exposure including R.M.S acceleration (A(8))” [99].

#### **1.5.6 WBV exposure patterns**

LBDs related to WBV are not an acute or short term effect, but rather a long-term accumulation of exposure [100, 101] that may result in pathological tissue changes, pain, and associated disability. According to Nielson and Jorgensen “it is probable that many years of exposure to the type of WBV, which occur in working machines may contribute to the genesis of injuries or disorders of the lower back” [98]. Given the complexity of WBV exposure, it is not clear what level, duration, or frequency patterns are related to LBD, and longitudinal data is rare. A study



by Bovenzi et al. on self-reported low back symptoms in urban bus drivers exposed to whole-body vibration found that elevated risk of LBD occurred at WBV exposure levels that were lower than the health-based exposure limits proposed by the International Standard ISO 2631/1 [102]. Palmer et al. also found that among those exposed to WBV, only a small proportion of these individuals exceeded the action level in the British Standards [71]. Mayton et al. also observed that WBV measured at the farm equipment operator/seat interface exceeded the recommended action level [103]. Futatsuka et al. found that WBV on the seats of combine harvesters and wheel tractors exceeded ISO 2631 exposure limits [104]. Rehn's risk assessment found that "vibration exposure in many ATVs used during work exceed recommended occupational exposure limits" [105]. Conversely, a study by Tiemessen et al. based on three WBV measurement metrics (VDV, RMS and RMQ) found no indication of a dose-response pattern between WBV exposure and 12-month prevalence of low back pain [106]. The inconsistent results regarding vibration levels might reflect the impact of differing durations, work cycles, and frequency spectra and underscores the importance of assessing exposure patterns not only exposure amounts.

## **1.6 Other options for exposure assessments**

WBV exposure can be assessed using different exposure assessment methods, including: direct assessment, self-report, observation, and the use of administrative data.

### **1.6.1 Observation**

Work place/occupational exposure can be assessed through the use of observational methods. Observation has been found to be suitable for assessing "categorical biomechanical exposure and occurrence of specific work task" [107]. This method can be carried out through field-based

or video-based approaches [108]. Observational methods, besides being “more suitable for use in recording and analysing simulated tasks” [109], is time consuming and has a limitation in terms of its suitability in workplace practical assessments [109]. Other challenges that may result from this approach include: issues with non-randomness and variability as pertains to work tasks which may not be captured by camera [108]. This approach is also prone to potential systematic biases which could be due to “behavioral effects from the presence of cameras and occluded views of the work” [108].

### **1.6.2 Self report**

Self-report is a data collection method that can be used to collect work place exposure data involving both physical and psychosocial factors [109]. Obtaining data through the use of self-report can be done in several ways including worker diaries, interviews, and questionnaires [109]. Although self-report is easy to adopt, inexpensive, appropriate for large samples, less time consuming, and does not require exposure experts [110], it has the limitations of low reliability and validity and hence is not a preferred choice for ergonomics [111]. Hardt et al. noted that self-report lacks the ability to assess work accurately, as workers might not be able to recall and report exposure to physical agents accurately [110]. For example, Spielholz et al. noted that “asking workers to estimate measures such as limb acceleration values, vibration levels, or joint moments was deemed not to be practical” [108].

### **1.6.3 Administrative data**

The utility of administrative data in occupational health assessments cannot be underestimated as it has contributed significantly in providing information on “worker’s compensation, hospital discharges, emergency department data” [112] and other “injuries and illnesses not reported

into employer-based surveillance systems” [112]. In spite of its several advantages which include obtaining information on large population with ease, low cost [113], and fewer resources required [114], it has limitations such as issues with accuracy of diagnostic information [113] and often incomplete or unreliable data [115]; handling such data requires specialized expertise [114].

## **1.7 Purpose of the study**

Although farmers with WBV exposure seem to be at higher risk for LBDs, the weight and quality of evidence is not enough to establish this association. Knowledge on the level, duration, and frequency patterns is needed to allow for prevention strategy development. Although works by other authors have investigated farming exposures broadly, their work rarely focuses on WBV exposure specifically. Therefore, this thesis will provide information on the association between LBDs and WBV exposures and important biopsychosocial covariates specifically by addressing the knowledge gap in two manuscripts: 1) association between WBV and LBDs in farmers in a systematic review; and 2) association between WBV and LBDs in farmers in a cohort study. This type of knowledge will fill existing gaps and help enable governments, occupational health agencies, and agricultural stakeholders to develop policies that promote safer working environments for farmers which would limit pain, loss of productivity, and temporary or permanent disabilities associated with LBDs.

## 1.8 References

1. Steenstra, I., et al., *Prognostic factors for duration of sick leave in patients sick listed with acute low back pain: a systematic review of the literature*. Occupational and environmental medicine, 2005. **62**(12): p. 851-860.
2. Driscoll, T., et al., *The global burden of occupationally related low back pain: estimates from the Global Burden of Disease 2010 study*. Annals of the rheumatic diseases, 2014. **73**(6): p. 975-981.
3. Marras, W., *Occupational low back disorder causation and control*. Ergonomics, 2000. **43**(7): p. 880-902.
4. De Beeck, R.O. and V. Hermans, *work-related low back disorders*. Brussels: Institute for Occupational Safety and Health, 2000.
5. WHO, *Drugs, Essential Policy, Medicines. Priority Medicines for Europe and the World: A Public Health Approach to Innovation*. 2004: World Health Organization.
6. Maetzel, A. and L. Li, *The economic burden of low back pain: a review of studies published between 1996 and 2001*. Best Practice & Research Clinical Rheumatology, 2002. **16**(1): p. 23-30.
7. Erick, P.N. and D.R. Smith, *Low back pain among school teachers in Botswana, prevalence and risk factors*. BMC musculoskeletal disorders, 2014. **15**(1): p. 359.
8. Tavafian, S.S., et al., *Low back pain education and short term quality of life: a randomized trial*. BMC Musculoskeletal Disorders, 2007. **8**(1): p. 21.
9. Punnett, L., et al., *Estimating the global burden of low back pain attributable to combined occupational exposures*. American journal of industrial medicine, 2005. **48**(6): p. 459-469.
10. Itoh, H., F. Kitamura, and K. Yokoyama, *Estimates of Annual Medical Costs of Work-related Low Back Pain in Japan*. Industrial health, 2013. **51**(5): p. 524-529.
11. Maniadakis, N. and A. Gray, *The economic burden of back pain in the UK*. Pain, 2000. **84**(1): p. 95-103.
12. Walker, B., R. Muller, and W. Grant, *Low back pain in Australian adults: the economic burden*. Asia-Pacific Journal of Public Health, 2003. **15**(2): p. 79-87.

13. David Kriebel, M.M.J., Pia Markkanen, Joel Tickner, *Lessons Learned Solutions for Workplace Safety and Health*. 2011.
14. Collins, J., *Safe patient handling lifting standards for a safer American Workforce*. CDC Congressional Testimony, 2010.
15. Waehrer, G., J.P. Leigh, and T.R. Miller, *Costs of occupational injury and illness within the health services sector*. International Journal of Health Services, 2005. **35**(2): p. 343-359.
16. Bevan, S., et al., *Fit For Work—Musculoskeletal disorders in the European workforce*. 1-143. The Work Foundation, 2009.
17. *Chiropractic Treatments*. [http://www.globalwellnesscentre.com/chiropractic\\_lowerback](http://www.globalwellnesscentre.com/chiropractic_lowerback).
18. Brennan, G., et al., *Lower back pain in physically demanding college academic programs: a questionnaire based study*. BMC musculoskeletal disorders, 2007. **8**(1): p. 67.
19. <http://www.cdph.ca.gov/programs/ohsep/Documents/Ind20Back07-10.pdf>.
20. Borenstein, D., "Low Back Pain," in Barker LR, Burton JR (eds):. *Principles of Ambulatory Medicine*. 1991.
21. Plante, D., M. Rothwell, and H. Tufo, *Managing the quality of care for low back pain*. The adult spine: Principles and practice, 1997: p. 85-105.
22. Work, F.E.A.f.S.a.H.a., *Inventory of socio-economic information about work-related musculoskeletal disorders in the Member States of the European Union*. Heterocycles, 2012. **85**(7): p. 8-11.
23. Spengler, D.M., Bigos, S. J., Martin, N. A., Zeh, J., Fisher, L., & Nachemson, A, *Back Injuries in Industry: A Retrospective Study: I. Overview and Cost Analysis*. Spine, 1986. **11**(3): p. 241-245.
24. Webster, B.S. and S.H. Snook, *The cost of 1989 workers' compensation low back pain claims*. Spine, 1994. **19**(10): p. 1111-1115.
25. WorkSafeBC, 2009.  
[http://www.worksafebc.com/publications/reports/statistics\\_reports/assets/pdf/stats2009.pdf](http://www.worksafebc.com/publications/reports/statistics_reports/assets/pdf/stats2009.pdf).
26. *Lower Back Pain - Back to Health Wellness Centre* 2009.  
<http://www.back2health4you.com/2014/10/lower-back-pain/>.

27. McGee, R., S. Bevan, and T. Quadrello, *Fit for Work? Musculoskeletal Disorders and the Canadian Labour Market*. The Work Foundation, 2009.
28. Hincapie, C.A., J.D. Cassidy, and P. Cote, *Is a history of work-related low back injury associated with prevalent low back pain and depression in the general population?* BMC Musculoskelet Disord, 2008. **9**: p. 22.
29. Nikolajsen, L., et al., *Pain and somatosensory findings in patients 3 years after total hip arthroplasty*. European journal of pain, 2009. **13**(6): p. 576-581.
30. Schäfer, A., T. Hall, and K. Briffa, *Classification of low back-related leg pain—a proposed patho-mechanism-based approach*. Manual therapy, 2009. **14**(2): p. 222-230.
31. Harris-Hayes, M., S.A. Sahrmann, and L.R. Van Dillen, *Relationship between the hip and low back pain in athletes who participate in rotation-related sports*. Journal of sport rehabilitation, 2009. **18**(1): p. 60.
32. Rostocki, A., *Back and Hip Pain*. <http://www.cure-back-pain.org/back-and-hip-pain.html>. 2013, Cure-Back-Pain.Org.
33. Thelin, A., *Work and health among farmers*. Scandinavian Journal of Social Medicine, 1980(Suppl. 22).
34. Stupar, M., et al., *The association between low back pain and osteoarthritis of the hip and knee: a population-based cohort study*. Journal of manipulative and physiological therapeutics, 2010. **33**(5): p. 349-354.
35. Suri, P., et al., *Low back pain and other musculoskeletal pain comorbidities in individuals with symptomatic osteoarthritis of the knee: data from the osteoarthritis initiative*. Arthritis care & research, 2010. **62**(12): p. 1715-1723.
36. Zhao, W., *Preventing Low Back Pain in Agriculture*. Rutgers NJAES Cooperative Extension. <https://njaes.rutgers.edu/pubs/publication.asp?pid=FS661>. 1992.
37. Griffin, P.J., *Safety and Health in Agriculture*. "Farming - a hazardous occupation – how to improve health & safety?". <http://www.europarl.europa.eu/document/activities/cont/201303/20130321ATT63633/20130321ATT63633EN.pdf>.

38. *Rural Development in the EU Statistical and Economic Information Report 2012.*  
[http://ec.europa.eu/agriculture/statistics/rural-development/2012/full-text\\_en.pdf](http://ec.europa.eu/agriculture/statistics/rural-development/2012/full-text_en.pdf).
39. Lee, W.J., E.S. Cha, and E.K. Moon, *Disease prevalence and mortality among agricultural workers in Korea.* Journal of Korean medical science, 2010. **25**(Suppl): p. S112-S118.
40. *Australian Bureau of Statistics. Australian farming and farmers. , in Australian Social Trends.* 2012.
41. *United States Department of Agriculture, Technical bulletins.*  
<https://books.google.ca/books?id=eywaJmIWRecC>. 1946(876-900).
42. *OCCUPATIONAL HEALTH DISPARITIES. Inputs: Occupational Safety and Health Risks.*  
<http://www.cdc.gov/niosh/programs/ohd/risks.html>.
43. Dupuis. H, G.Z., *The Effects of Whole-Body Vibration* 1986 Springer-Verlag Berlin Heidelberg
44. Park, H., et al., *Risk factors for back pain among male farmers: analysis of Iowa Farm Family Health and Hazard Surveillance Study.* American journal of industrial medicine, 2001. **40**(6): p. 646-654.
45. Osborne, A., et al., *Musculoskeletal disorders among Irish farmers.* Occupational medicine, 2010: p. kqq146.
46. Gupta, G., *Prevalence of Musculoskeletal Disorders in Farmers of Kanpur-Rural, India.* Journal of Community Medicine & Health Education, 2013.
47. Rosecrance, J., G. Rodgers, and L. Merlino, *Low back pain and musculoskeletal symptoms among Kansas farmers.* American journal of industrial medicine, 2006. **49**(7): p. 547-556.
48. Liu, X., et al., *Back pain among farmers in a northern area of China.* Spine, 2012. **37**(6): p. 508.
49. Von Essen, S.G. and S.A. McCurdy, *Health and safety risks in production agriculture.* Western Journal of Medicine, 1998. **169**(4): p. 214.
50. Pincus, T., et al., *Twenty-Five Years With the Biopsychosocial Model of Low Back Pain—Is It Time to Celebrate? A Report From the Twelfth International Forum for Primary Care Research on Low Back Pain.* Spine, 2013. **38**(24): p. 2118-2123.

51. Gerdle, B., et al., *Chronic musculoskeletal pain: review of mechanisms and biochemical biomarkers as assessed by the microdialysis technique*. Journal of pain research, 2014. **7**: p. 313.
52. Macleod, J. and G.D. Smith, *Psychosocial factors and public health: a suitable case for treatment?* Journal of Epidemiology and Community Health, 2003. **57**(8): p. 565-570.
53. Clays, E., et al., *The impact of psychosocial factors on low back pain: longitudinal results from the Belstress study*. Spine, 2007. **32**(2): p. 262-268.
54. Feldt, K.A., *Correlations Between Biopsychosocial Variables and Low Back Pain*. 2003.
55. Biglarian, A., et al., *Low back pain prevalence and associated factors in Iranian population: findings from the national health survey*. Pain research and treatment, 2012. **2012**.
56. Deyo, R.A. and Y.-J. Tsui-Wu, *Descriptive epidemiology of low-back pain and its related medical care in the United States*. Spine, 1987. **12**(3): p. 264-268.
57. Chevan, J. and P.A. Clapis, *Physical Therapy Management of Low Back Pain: A Case-based Approach*. 2013: Jones & Bartlett Publishers.
58. DePalma, M.J., J.M. Ketchum, and T.R. Saullo, *Multivariable analyses of the relationships between age, gender, and body mass index and the source of chronic low back pain*. Pain Medicine, 2012. **13**(4): p. 498-506.
59. Heuch, I., et al., *Body mass index as a risk factor for developing chronic low back pain: A Follow-up in the Nord-Trøndelag Health Study*. Spine, 2013. **38**(2): p. 133-139.
60. Waterman, B.R., P.J. Belmont, and A.J. Schoenfeld, *Low back pain in the United States: incidence and risk factors for presentation in the emergency setting*. The Spine Journal, 2012. **12**(1): p. 63-70.
61. Teschke, K., et al., *Whole Body Vibration and Back Disorders Among Motor Vehicle Drivers and Heavy Equipment Operators A Review of the Scientific Evidence*. Occupational Hygiene, 1999. **6**: p. 123.
62. Heliövaara, M., *Risk factors for low back pain and sciatica*. Annals of Medicine, 1989. **21**(4): p. 257-264.



63. Shiri, R., et al., *The association between smoking and low back pain: a meta-analysis*. The American journal of medicine, 2010. **123**(1): p. 87. e7-87. e35.
64. DEYO, R.A. and J.E. BASS, *Lifestyle and low-back pain: the influence of smoking and obesity*. Spine, 1989. **14**(5): p. 501-506.
65. Osborne, A., et al., *Risk factors for musculoskeletal disorders among farm owners and farm workers: A systematic review*. American journal of industrial medicine, 2012. **55**(4): p. 376-389.
66. Walker-Bone, K. and K. Palmer, *Musculoskeletal disorders in farmers and farm workers*. Occupational medicine, 2002. **52**(8): p. 441-450.
67. Osborne, A., et al., *Work-related musculoskeletal disorders among Irish farm operators*. American journal of industrial medicine, 2013. **56**(2): p. 235-242.
68. Cvetanovic, B. and D. Zlatkovic, *Evaluation of wholebody vibration risk in agricultural tractor drivers*. Bulgarian Journal of Agricultural Science, 2013. **19**(5): p. 1155-1160.
69. Shivakumara, B. and V. Sridhar, *Study of vibration and its effect on health of the motorcycle rider*. Online Journal of Health and Allied Sciences, 2010. **9**(2).
70. Levy, B.S., et al., *Occupational and Environmental Health*. 2011: p. 235-238.
71. Palmer, K.T., et al., *Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey*. Occupational and Environmental Medicine, 2000. **57**(4): p. 229-236.
72. Manchikanti, L., *Epidemiology of low back pain*. Pain physician, 2000. **3**(2): p. 167-192.
73. Chen, J.-C., et al., *Using "exposure prediction rules" for exposure assessment: an example on whole-body vibration in taxi drivers*. Epidemiology, 2004. **15**(3): p. 293-299.
74. Varghese, M., et al. *A biomechanical and MRI analysis of back pain among drivers exposed to tractor vibrations*. in *2000 International Conference on the Biomechanics of Impact*. 2001. International Research Council on the Biomechanics of Impact BRON Cedex,, France.
75. Bovenzi, M., et al., *An epidemiological study of low back pain in professional drivers*. Journal of Sound and Vibration, 2006. **298**(3): p. 514-539.

76. Putz-Anderson, V., et al., *Musculoskeletal disorders and workplace factors*. A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati: National Institute for Occupational Safety and Health, 1997.
77. Palmer, K.T., et al., *Case-control study of low-back pain referred for magnetic resonance imaging, with special focus on whole-body vibration*. Scand J Work Environ Health, 2008. **34**(5): p. 364-373.
78. WorkSafeBC, *WorkSafeBC Evidence-Based Practice Group 2008*.  
[http://www.worksafebc.com/health\\_care\\_providers/Assets/PDF/whole\\_body\\_vibration\\_low\\_back\\_pain.pdf](http://www.worksafebc.com/health_care_providers/Assets/PDF/whole_body_vibration_low_back_pain.pdf).
79. Waters, T., et al., *The impact of operating heavy equipment vehicles on lower back disorders*. Ergonomics, 2008. **51**(5): p. 602-636.
80. Bovenzi, M. and C. Hulshof, *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, 1999. **72**(6): p. 351-365.
81. Solecki, L., *Studies of farmers' annual exposure to whole body vibration on selected family farms of mixed production profile*. Annals of Agricultural and Environmental Medicine, 2012. **19**(2).
82. Hostens, I. and H. Ramon, *Descriptive analysis of combine cabin vibrations and their effect on the human body*. Journal of sound and vibration, 2003. **266**(3): p. 453-464.
83. Chen et al. *Predictors of whole-body vibration levels among urban taxi drivers*. Ergonomics, 2003. **46**(11).
84. Bust, P.D., *Contemporary Ergonomics 2008: Proceedings of the International Conference on Contemporary Ergonomics (CE2008), 1-3 April 2008, Nottingham, UK*. 2008: CRC Press.
85. European Agency for Safety and Health at Work. *EUROPEAN RISK OBSERVATORY REPORT. Workplace exposure to vibration in Europe: an expert review*.  
[https://osha.europa.eu/en/publications/reports/8108322\\_vibration\\_exposure](https://osha.europa.eu/en/publications/reports/8108322_vibration_exposure). 2008.

86. Griffin, M., *Handbook of human vibration*. Academic, London, 1990.
87. Darby, A.M., *Whole-body vibration and ergonomics toolkit. Research Report*  
<http://www.hse.gov.uk/research/rrpdf/rr612.pdf>. 2008.
88. *Whole-body vibration. The Control of Vibration at Work Regulations 2005 Guidance on Regulations.* [http://www.gub.ac.uk/safety-reps/sr\\_webpages/safety\\_downloads/whole\\_body\\_vibration.pdf](http://www.gub.ac.uk/safety-reps/sr_webpages/safety_downloads/whole_body_vibration.pdf).
89. Bovenzi, M. and A. Betta, *Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress*. *Applied ergonomics*, 1994. **25**(4): p. 231-241.
90. *International Organization for Standardization 1985 Evaluation of human exposure to whole body vibration - Part 1: General requirements ISO 263111*, Geneva.
91. Newell, G., N.J. Mansfield, and L. Notini, *Survey of heavy equipment operators whole-body vibration profiles*. *Contemporary Ergonomics*, 2008. **2008**: p. 203.
92. Fahy, F. and J. Walker, *Fundamentals of noise and vibration*. 1998: CRC Press.
93. Servadio, P. and N.P. Belfiore, *Influence of tyres characteristics and travelling speed on ride vibrations of a modern medium powered tractor Part II, Evaluation of the Health Risk*. *Agricultural Engineering International: CIGR Journal*, 2013. **15**(4): p. 132-138.
94. Blood, R., et al., *Whole body vibration exposures in metropolitan bus drivers: A comparison of three seats*. *Journal of Sound and Vibration*, 2010. **329**(1): p. 109-120.
95. Sandover, J., *High acceleration events: An introduction and review of expert opinion*. *Journal of Sound and Vibration*, 1998. **215**(4): p. 927-945.
96. Boshuizen, H.C., P.M. Bongers, and C.T. Hulshof, *Self-reported back pain in tractor drivers exposed to whole-body vibration*. *International archives of occupational and environmental health*, 1990. **62**(2): p. 109-115.
97. Boshuizen, H.C., C.T. Hulshof, and P.M. Bongers, *Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration*. *International archives of occupational and environmental health*, 1990. **62**(2): p. 117-122.
98. R Nielson, K.J., *Advances In Industrial Ergonomics And Safety V 1ed. Vol. 5*. 1993: CRC Press.

99. Bovenzi, M., *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, 2009. **82**(7): p. 893-917.
100. Dupuis H, Z.G., *Epidemiological research on professional groups exposed to vibration, In: Dupuis H, Zerlett G, eds. The effects of whole-body vibration. Berlin: SpringerVerlag, 1986: 91-6.*
101. McDonald, C., *Epidemiology of Work Related Diseases*. 2nd ed. 2000: BMJ Books.
102. Bovenzi, M. and A. Zadini, *Self-reported low back symptoms in urban bus drivers exposed to whole-body vibration*. Spine, 1992. **17**(9): p. 1048-1059.
103. Mayton, A., et al., *Jarring/jolting exposure and musculoskeletal symptoms among farm equipment operators*. International Journal of Industrial Ergonomics, 2008. **38**(9): p. 758-766.
104. Futatsuka, M., et al., *Whole-body vibration and health effects in the agricultural machinery drivers*. Industrial health, 1998. **36**(2): p. 127-132.
105. Rehn, B., *Musculoskeletal disorders and whole-body vibration exposure among professional drivers of all-terrain vehicles*. <http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A142690&dswid=-7187>, in Umeå University medical dissertations, ISSN 0346-6612 ; 852. 2004.
106. Tiemessen, I.J., C.T. Hulshof, and M. Frings-Dresen, *Low back pain in drivers exposed to whole body vibration: analysis of a dose–response pattern*. Occupational and environmental medicine, 2008. **65**(10): p. 667-675.
107. Mathiassen, S.E., J.A. Jackson, and L. Punnett, *Statistical performance of observational work sampling for assessment of categorical exposure variables: a simulation approach illustrated using PATH data*. Annals of occupational hygiene, 2013: p. met063.
108. Spielholz, P., et al., *Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors*. Ergonomics, 2001. **44**(6): p. 588-613.
109. David, G., *Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders*. Occupational medicine, 2005. **55**(3): p. 190-199.

110. Hardt, J.S., et al., *A comparison of exposure assessment approaches: lung cancer and occupational asbestos exposure in a population-based case-control study*. Occupational and environmental medicine, 2013: p. oemed-2013-101735.
111. Li, G. and P. Buckle, *Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods*. Ergonomics, 1999. **42**(5): p. 674-695.
112. Levy, B.S., *Occupational and environmental health: recognizing and preventing disease and injury*. 2006: Lippincott Williams & Wilkins.
113. Muggah, E., et al., *Ascertainment of chronic diseases using population health data: a comparison of health administrative data and patient self-report*. BMC public health, 2013. **13**(1): p. 16.
114. Lash, T.L., et al., *Methodology, design, and analytic techniques to address measurement of comorbid disease*. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 2007. **62**(3): p. 281-285.
115. Grosh, M.E., *For protection and promotion: The design and implementation of effective safety nets*. 2008: World Bank Publications.

## Chapter 2: Manuscript 1

### **Association between whole body vibration and low back disorders in farmers: a systematic review**

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#### **Contribution Statement:**

SKE's role was to develop the research questions and secondary screening/extraction instruments, conduct secondary screening and data extraction, and to synthesize and summarize results. SKE led the drafting of the manuscript.

## 2.1 Abstract

**Background:** Low back disorders (LBDs) are the most common musculoskeletal problem among farmers, with higher prevalence rates than in other occupations. Farmers who operate tractors and other types of machinery can have substantial exposure to whole body vibration (WBV). Although there appears to be an association between WBV and LBDs, the causal relationship is not clear.

**Purpose:** This systematic review investigates the association between whole body vibration and low back disorders among farmers.

**Methods:** Nine databases were searched using groups of terms for two concepts: ‘farming’ and ‘low back disorder’. Screening, data extraction and quality assessment was performed by two reviewers independently. The population was adult farmers or agricultural workers globally irrespective of sex. The intervention was considered to be WBV exposure, such tractor, combine and ATV use. The control was no exposure or low exposure to WBV and the outcome was low back disorders.

**Results:** After 276 full texts screened, 12 articles met our selection criteria and were used to analyze WBV as a risk factor for LBD. Three were case-control, 6 cross-sectional and 3 retrospective cohorts. Four studies showed no association between WBV and LBDs, 4 studies showed a positive association and the remaining 4 studies results were mixed depending on the exposure or the outcome measure.

**Conclusion:** A firm conclusion is difficult due to heterogeneity in, LBDs definition, type of farm commodity, study design, and statistical strategy. Direct comparisons and synthesis were not

possible. Although retrospective cohort studies tended to show a relationship, future studies with a prospective cohort design could help clarify this association further. Future research should focus on standardization of LBDs definition and WBV exposure measures.

## 2.2 Introduction

Low back disorders (LBDs), a term which includes both low back pain and low back injuries [1], are a significant public health concern with high social and economic costs [2, 3]. Besides LBDs being most common musculoskeletal problem in farmers, with higher prevalence rates than in other occupations [4], they account for about one-third of work-related disability globally [5]. To this effect, farmers are particularly vulnerable to developing LBDs; this may arise from their work which involves occupational exposure activities that are probable risk factors for the development of LBDs [6, 7]. In particular, farmers who operate tractors and other types of machinery such as combines and all-terrain vehicles are exposed to whole body vibration [8]. Vibration often accompanies operation of farm equipment and is caused by random (unevenness of road or soil profile) and systematic (moving elements within the machine (vehicle) or its attached implements) [9] vibration.

The relationship between WBV and LBDs is not fully clear. Results of reviews have been mixed, with some supporting the relationship [10-13] and some not [14-16]. However, these reviews considered occupations in general, not specifically farming, where findings appear to be more consistent in terms of long exposure to vibration prone vehicles or machinery. Lee et al. reported the uniqueness of farming in terms of workers' traits and behaviours, setting and organizational structure as compared to other occupations [17]. Farmers are indeed unique in



many respects, including the probability of more exposure to WBV over their lifetimes than other occupations. As stated by Griffin, “farms are homes populated by children and elderly”[18]. Farmers are employed younger than in other occupations [19, 20], and they are more likely to continue working well beyond the age at which most other workers retire [21]. Farming is characterised by a high degree of self-employment and long working hours [21]. In addition, farmers may use a variety of machinery throughout the year.

Although farmers with exposure to whole body vibration seem to be at higher risk for LBDs, a review has never been conducted to evaluate the relationship between WBV and LBDs specifically in this occupation. This knowledge gap limits ability to establish focused and tailored preventative strategies that will help promote safer working environments for farmers. Therefore, the objective of this systemic literature review is to investigate the association between WBV and LBDs in farmers.

## 2.3 Methodology

This systematic review is one part of a larger systematic review on LBD in farmers. An *a priori* protocol was registered on PROSPERO (CRD42014013247), and is available on the *Centre for Reviews and Dissemination website* [22].

Although this systematic review did not study interventions, the PICO framework [23, 24] has been applied to provide a structure for the study. In terms of population, this review focused on adult farmers or agricultural workers globally, including both males and females. As mentioned earlier, the focus of this review was not an intervention *per se* but rather exposure to WBV. However, Lichtenstein et al. suggested that, in the absence of intervention, exposure can be considered [25]. Hence, the effects of WBV resulting from use of farm machinery or agricultural vehicles are being investigated in this review. Control in the case of this review can be considered those with no exposure or very low exposure to WBV. The outcome was low back disorders, which includes low back pain, back pain, and lumbago. In terms of type of study, this review considered wide range of studies which include: observational studies and RTCs. No restriction on date of publication was applied.

### 2.3.1 Search Strategy

Databases searches for full text publications were conducted in OVID Medline, Web of Science, Cumulative Index to Nursing and Allied Health Literature (CINAHL), SCOPUS, OVID EMBASE, OSH References, PEDro, OTSeeker and PubMed. In addition, Canadian grey literature was searched, but nothing was included. The search was based on two groups of search terms: 'Farming' and 'Low back disorder'. No limits in date of publication were applied in the literature search, but we only included English language full text publications.

### 2.3.2 Screening and selection Process

All articles identified in the initial search were screened individually by two reviewers starting from the title, abstract, and full-text stages. The screening of articles found to be potentially relevant to the study were assessed based on the criteria that the population must be adult farmers or agricultural workers globally irrespective of sex, those with exposure to WBV by operating farm vehicles such as tractor, ATV and combine, may come from any part of the world, with low back disorders, low back pain and lumbago as an outcome. There were no restriction on date of publication and the type of study design used. In order to adequately address the research question “what is the strength of the association between WBV and LBDs among farmers”, additional two more stringent inclusion criteria were considered which include: 1) study must focus or provide data on the relationship between low back disorder and whole body vibration, and 2) the reporting of inferential statistics to assess this relationship.

Studies focusing on only children were not included. Canadian grey literature was searched, but nothing was included. Any disagreements that arose were discussed by the two reviewers; these meetings created an opportunity to improve upon the interpretation of decision rules for both the inclusion and exclusion criteria so as to enhance the screening process. The summary of the process of searching, screening, and extraction is found in figure 2.

### 2.3.3 Data Extraction

The data extraction phase of this systematic review focused on the primary research question “what is the strength of the association between whole body vibration and low back disorder among farmers?” Data extraction captured information such as exposure assessment type, socio-demographics characteristics, study design, population, sampling strategy used by

studies, commodity involved, location (region, country). Data were extracted by two reviewers independently, and then reconciled through discussion. Disagreements that arose during the reconciliation process were discussed and resolved at team meetings.

#### **2.3.4 Study Quality Assessment**

The assessment of the quality of the studies involved the assessment of the risk of bias in accordance with the tools developed by both Hoy et al. [26] and Elm et al.(STROBE) [27]. The assessment process included binary (Yes/No) questions such as “was the sampling frame a true or close representation of the target population?” “Was the likelihood of a non-response bias minimal?” (see Appendix D). In addition, the measure of risk with significance level and confidence interval, study finding, consideration of confounders (see Appendix E), and the quality of low back disorder definition were assessed. As with other aspects of data extraction, the quality of the study was rated independently by two reviewers.

#### **2.3.5 Forest Plot**

Forest plots were employed to graphically represent the point estimates of association and the variability of findings. A forest plot was developed for the subset of studies which met the following criteria: reported an odds ratio based on 95% confidence interval; reported LBDs prevalence of 52 weeks and used self-reported duration via a survey for exposure assessment. In the case of two or more exposure categories, the odds ratio of the highest exposure category was used. The plot was developed in MedCalc software [28].

## 2.4 Results

Figure 2 shows the results of searching and screening steps for the systematic review. In the search, 694 titles were found, of which 276 made it to full text stage. After full texts were screened, 12 papers were found to analyze WBV as a risk factor for LBD. The 12 studies used various study designs; three were case-control, six cross-sectional, and three retrospective cohorts.

Table 1 summarizes the findings of the population characteristics and employment context of the 12 studies. In terms of sex, five studies were on both males and females, four studies were on only male farmers, one on only female and the remaining two studies did not specify. Out of the 12 studies included, only 4 studies provided information on age and the ages ranged from 18-95 years. In terms of commodity, most (5) studies focused on farmers who were involved in mixed farming commodities, one on animal product, three on crop production, and three did not specify the type of commodity produced. Overall, the majority of studies were from developed and industrialised nations.

Table 2 summarizes results on exposure assessment methods and characteristics of included studies. Majority of studies (8) used only self-report, 2 used only direct measurement and the remaining 2 used a combination of direct and self-report. In addition, majority of studies summarized exposure based on categories. In terms of exposure dimensions, most included studies (6) used durations.

Table 3 summarizes findings on the quality of research assessment of included studies. The results revealed that Questions on “random sampling” and “non-response bias” were not

addressed by five of the studies. However, several questions were addressed well by the majority of studies, including: “representative sampling frame”, “low back disorder definition”, “same mode of data collection” and “direct data collection”.

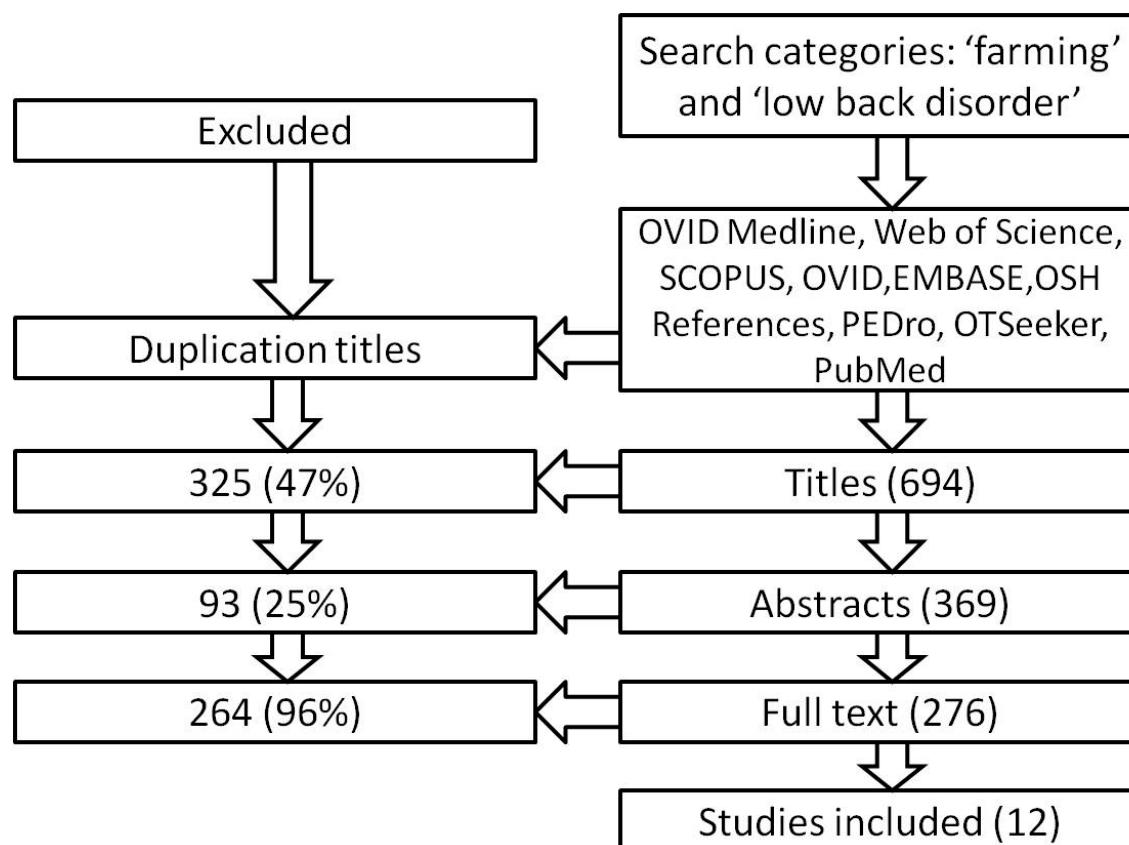


Figure 2: Results of searching and screening steps for the systematic review

**Table 1: Summary of Population Characteristics and Employment Context of Included Studies**

Reference	Study Design	Sex and demographics	Commodity	Employment context	Sample Size(n)	Region
<b>Milosavljevic et al. 2012[29]</b>	Cross-sectional	Males (85%) Females (15%).	Dairy, Beef, Sheep and mixed stock,	Self-employed farmers and rural workers	130	New Zealand
<b>Bernard et al. 2011[30]</b>	Cross-sectional	Males (72%) Females (18%). Gender considered	Fruit	Vineyard workers	3947	France
<b>Hathorn et al. 2009[31]</b>	Cross-sectional	(100%) Women older than 18yrs.ethnicity (white/non-white)	Hauling Animals Beef and Hay		657	Louisiana, USA
<b>Hartman et al. 2006[32]</b>	Case-control	Males (100%)	Dairy, Pig, Poultry, Arable, Horticulture, and Mushroom	Self-employed farmers	1156	Netherlands
<b>Gomez et al. 2003[33]</b>	Cross-sectional	Males (62% ) Females (38%). Age from 18-95 99% white and 1% Hispanic	Dairy, Other livestock, Cash crop, Vegetable, Fruit, and Horticultural	Owner/ Operator Worker Resident	1706	New York, USA
<b>Toren et al. 2002 [34]</b>	Cross-sectional	Males (89%) 10% females. Gender considered	Crops, Milk, Meat, Swine, Poultry, Sheep, Potato, Forestry, Vegetables	Farm workers	1075	Uppsala, Sweden



Reference	Study Design	Sex and demographics	Commodity	Employment context	Sample Size (n)	Region
<b>Kumar et al. 1999 [35]</b>	Retrospective cohort	Not Specified	Not specified	Drivers of agricultural tractors	100	India
<b>Boshuizen et al. 1990[36]</b>	Retrospective cohort	Males (100%)	Not specified	Drivers of agricultural tractors	577	Netherlands
<b>Boshuizen et al. 1990[37]</b>	Retrospective cohort	Males (100%)	Not specified	Drivers of agricultural tractors	499	Netherlands
<b>Hartman et al. 2005[38]</b>	Case-Control	Not Specified Gender considered	Dairy farming, Pig husbandry, Poultry farming, Arable farming, Horticulture, Bulb farming, Fruit, Plant, Mushroom	Self-employed farmers	198	Netherlands
<b>Xiao et al.2013[39]</b>	Cross-sectional	Men (55%) Women (45%). Age from 18-55yr ethnicity ( Mexican, Central, Or South American, Hispanic or Latino )	Melon, Tomatoes, nuts, grapes, Cotton	Migrant and Seasonal farm workers	759	California, USA
<b>Bovenzi et al. 1994 [40]</b>	Case-control	100% Males Aged 25-65 years	Apple trees, vineyards	Drivers of agricultural tractors	1155	Italy

**Table 2: Summary of Exposure Assessment Methodologies and Characteristics of Included Studies**

Reference	Exposure Metrics	Exposure Assessment and Sampling Strategy Used	Results (risk of LBD with exposure to WBV)
<b>Milosavljevic et al. 2012 [29]</b>	Vibration dose value ISO 2631:>17m/s <sup>1.75</sup> (Continuous)	Convenience sampling Direct exposure measurement based on	<b>LBP 12- month</b> OR =1.01, 95% CI 0.94-1.08, P = 0.81
		1 hour exposure	<b>LBP 12-month</b> OR =1.03, 95%CI 0.94-1.13, P = 0.50
	Level Shock Mpa	Full day's exposure	<b>LBP 12- month</b> OR=1.19, 95% CI 0.96-1.49, P = 0.12
<b>Bernard et al. 2011 [30]</b>	Duration measured in years (Categorical)	Random sampling stratified method Self-reported exposure via postal survey	OR=1.439, 95% CI 1.15-1.80
<b>Hathorn et al. 2009 [31]</b>	Duration: Days on tractors (Categorical). Exceeding 20 hours per week	Stratified, random sampling. Self-reported via phone interview 1 to 20 based on hours per week	1 to 20 days OR=1.23, 95% CI 0.81-1.86 >20 days OR=1.35 95%CI 0.86-2.11
<b>Hartman et al. 2006 [32]</b>	Duration: Hours/year. (Categorical). Driving tractor exceeding 1000 hr per year, Duration of work in hours/week >60	Cases; not specified. Controls; random sampling. Self-reported exposure via postal questionnaire Past 12 months	>1,000hr/Year OR=2.44, 95% CI 0.95-6.43
<b>Gomez et al. 2003 [33]</b>	Duration: Hours per day in past year Categorical. Exceeding 4 hours per day in the past year: 0, 1-99, 100-199, ≥ 200	Self-reported via phone interview based on hours on average work on farm during each season in the past year	OR=1.51, 95%CI 1.20-1.89
<b>Toren et al. 2002 [34]</b>	Duration: Per person year (Continuous). More than 30h/week	Self-reported exposure via postal questionnaire based on hours of tractor driving in the previous year	OR=0.92, 95%CI 0.82-1.03
<b>Kumar et al. 1999 [35]</b>	Frequency: measured in Hertz Frequency of 1 Hz and upper frequency of 100Hz. (Categorical)	Direct exposure measurement/ questionnaire based interview	P = 0.015

Reference	Exposure Metrics	Exposure Assessment and Sampling Strategy Used	Result
Boshuizen et al. 1990 [36]	Exceeding IOS-2631 exposure limit (Categorical) <b>Vibration dose in years</b> 0-2.5	Matching. Self-reported exposure via postal questionnaire based on number of hours driven daily	Overall P-value M-H=0.001 & Wald =0.005 OR =1.80, 90%CI 1.11-2.9
	2.5-5		OR=1.78, 90%CI 1.04-3.1
	>5		OR=2.8., 90%CI 1.64-5.0
	<b>Vibration magnitude (<math>ms^{-2}</math>)</b> 0.3-0.55		OR= 1.98 90%CI 0.98-4.0
	0.55-0.7		OR=1.66 90%CI 0.82-3.4
	0.7-0.9		OR=2.10 90%CI 1.07-4.1
	>0.9		OR=1.38 90%CI 0.52-3.7
	<b>Duration of exposure in years</b> 0-5		OR= 2.44 90%CI 0.84-7.1
	5-10		OR=2.5 90%CI 0.85-7.6
	>10		OR = 3.6 90%CI 1.21-11
Boshuizen et al. 1990 [37]	Duration; Magnitude exceeding $0.4m/s^2$ (Categorical)	Convenience sampling Direct exposure measurement based on number of hours driven daily	
	520 weeks of exposure.		RR =1.14, 90%CI 0.88-1.48
	A 5yrs $m^2/s^4$ dose exposure <b>vibration dose in year <math>m^2/s^4</math></b> 0.5-2.5		RR=1.13, 90%CI 0.85-1.50 <b>Incident density ratio (IDR)</b> IDR 0.97 90%CI 0.59-1.61
	2.5-5.0		IDR 1.51 90%CI 0.92-2.5
	>5		IDR 1.45 90%CI 0.84-2.5

Reference	Exposure Metrics	Exposure Assessment and Sampling Strategy Used	Result
<b>Hartman et al. 2005 [38]</b>	Duration. Exceeding 500h/year (medium exposure). Reference category 0-250h/year. (Categorical) 251-500 h/year  >500h/year	Random sample. Self-reported exposure via postal questionnaire based on hours per year	OR=1.27, 95%CI 0.60-2.70, P = 0.533  OR=1.71, 95%CI 1.08-2.71 P = 0.021
<b>Xiao et al.2013 [39]</b>	Duration. More than 40h/week (Categorical)  1<60 ≥60  1<60 ≥60	Stratified random sampling. Self-reported exposure via personal interview based on number of hours per week	<b>Men</b>  OR =0.36, 95%CI 0.08-1.58 OR =2.16, 95%CI 1.02-4.54 <b>Women</b> OR=1.57, 95%CI 0.16-15.81 OR=3.39, 95%CI 0.52-21.13
<b>Bovenzi et al.1994 [40]</b>	Duration/years and Vibration dose value(years m <sup>2</sup> /s <sup>4</sup> ).ISO 2631/1 Standards in years m <sup>2</sup> /s <sup>4</sup> /tractor driving years above 5 years. (Categorical) Tractor driving years 5-15 16-25 >25 Vibration dose <15 15-30 >30	Direct exposure measurement/questionnaire based interview based on number of hours per year and daily exposure respectively	<b>12 month-LBP</b> OR=2.65 95%CI 1.68-4.18 OR =2.31 955CI 1.46-3.64 OR =2.74 95%CI 1.69-4.45 <b>12 month-LBP</b> OR =2.33, 95%CI 1.48-3.67 OR =3.04, 95%CI 1.92-4.82 OR =2.36, 95%CI 1.48-3.74
<b>Confounders*</b> Toren et al. gender, age Xiao et al.: age, years working in agriculture, and smoke Hartman et al: BMI, smoking			*OR=Odds ratio CI= Confidence interval M-H=Mantel Haenszel

**Table 3: Research Quality, as Assessed by Hoy Tool and STROBE, of Articles Linking WBV and LBDs**

Reference	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
<b>Milosavljevic et al. 2012 [29]</b>	Y	N	Y	Y	Y	4	Y	Y	Y	Y
<b>Bernard et al. 2011 [30]</b>	Y	Y	Y	Y	Y	4	Y	Y	Y	Y
<b>Hathorn et al. 2009 [31]</b>	Y	Y	N	Y	N	N/S	Y	Y	N	N
<b>Hartman et al. 2006 [32]</b>	Y	Y	N	Y	Y	3	Y	Y	Y	Y
<b>Gomez et al. 2003 [33]</b>	Y	N	Y	Y	Y	5	Y	Y	Y	Y
<b>Toren et al. 2002 [34]</b>	Y	Y	N	Y	Y	5	Y	Y	Y	Y
<b>Kumar et al. 1999 [35]</b>	Y	N	Y	Y	Y	4	Y	Y	Y	Y
<b>Boshuizen et al. 1990 [36]</b>	Y	N	Y	Y	Y	2	N	N	N	N
<b>Boshuizen et al 1990 [37]</b>	N	N	N	Y	Y	2	N	Y	N	N
<b>Hartman et al 2005 [38]</b>	Y	Y	Y	Y	Y	3	Y	Y	Y	Y
<b>Xiao et al.2013 [39]</b>	Y	Y	Y	Y	Y	4	Y	Y	Y	Y
<b>Bovenzi et al. 1994 [40]</b>	N	Y	N	Y	Y	5	Y	Y	Y	Y

N/S-Not specified\*

Q1-Representative Sampling Frame

Q2-Random Sampling

Q3-Non-Response Bias

Q4-Direct Data Collection

Q5-Low Back Disorder Definition

Q6-Quality of the Low Back Disorder Definition (scale 1, low-5, high)

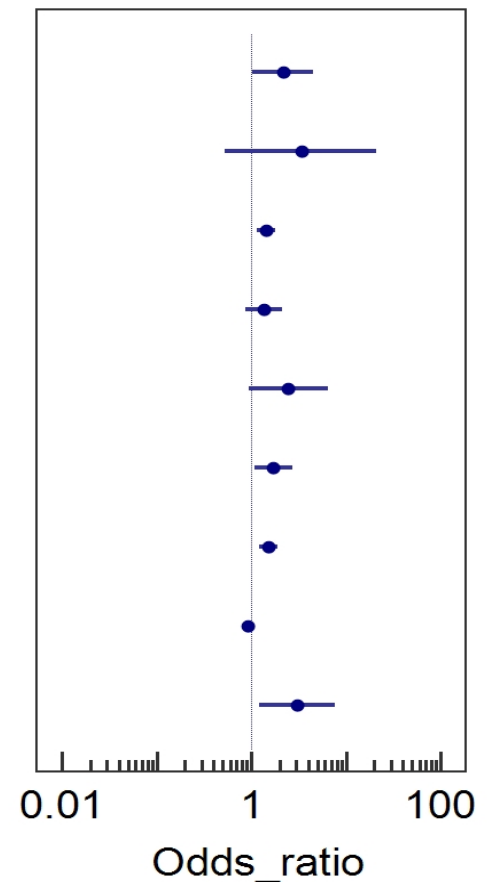
Q7-Study Instrument Validity/Reliability

Q8- Same Mode of Data Collection

Q9-Appropriate Length of Prevalence Period

Q10-Appropriate Numerator and Denominator

Xiao et al.2013 Men (cross-sectional)  
 Xiao et al.2013 Women (cross-sectional)  
 Bernard et al. 2011 (cross-sectional)  
 Hathorn et al. 2009 (cross-sectional)  
 Hartman et al. 2006 (case-control)  
 Hartman et al. 2005 (case-control)  
 Gomez et al. 2003 (cross-sectional)  
 Toren et al. 2002 (cross-sectional)  
 Kumar et al. 1999 (retrospective cohort)



**Figure 3: Forest plot of studies linking WBV exposure to risk of LBDs. Included studies were studies that reported LBD prevalence of several weeks or longer, used survey for exposure assessment, exposure dimension must be in duration, reported an odds ratio based on 95% confidence interval.**

## 2.5 Discussion

The present review identified 12 articles that assessed of the association between whole body vibration and low back disorders in farmers. Four studies showed no association between WBV and LBDs, four studies showed a positive association between WBV and LBDs, and the remaining four studies showed mixed association between WBV and LBDs depending on the exposure categories. Given the variability in results, study designs, and types of measures, it is not possible to make a conclusive statement on association between WBV and LBDs among farmers. However, insight into this relationship and the state of knowledge represented by the

literature can be attained by considering the studies' designs, settings, and exposure assessment methodologies.

### 2.5.1 Study Design and Statistical Approaches

This review included several types of studies, involving different statistical strategies to identify a relationship between LBDs and WBV. Most studies used odds ratio [29-34, 36, 38-40] in quantifying the relationship between WBV and LBDs, one used p-value from chi-square test of independence [35], and the remaining one used both relative risk and rate ratio [37]. The collapsibility property keeps the size of the risk ratio constant if a non-confounding variable is adjusted; since odds ratios do not have this property, comparing them to relative risk is inappropriate [42]. The heterogeneity in the measure of association used to quantify the association between WBV and LBDs also made a firm conclusion difficult. In addition, the statistical approaches (e.g., chi square, logistic model, and Cox proportional hazard model) used by studies also contributed to the inconclusiveness of the association between WBV and LBDs. The forest plot in figure 3 shows a positive association between WBV and LBDs in four of the studies [30, 33, 35, 38], three did not show any significant association [31, 32, 34] and the remaining one showed a mixed association [39]. The point estimates of studies which did not find any association were OR: 1.35 [31], 0.92 [32], and 2.44 [34]. This is sub-optimal, since "several confounding factors make it difficult to determine the relation between back problems and WBV" [35]. The articles did not consistently account for confounders such as age, sex, body mass index (BMI), education, height, and weight using multivariate analysis. Some of the studies reported results based on multivariate analysis and also adjusted for potential confounding factors and others reported only bivariate analysis. For example, nine studies

included confounders [30, 32-34, 36-40], and the others did not [29, 31, 35]. Confounders included in the studies were age, body mass index (BMI), smoking, education, years in job, sport activity, marital status, height, weight, and time sitting. It is unclear whether significant bivariate associations would persist after accounting for confounding. Most confounders considered by studies were consistent with other findings [43, 44], however, studies were silent on psychological factors such as stress-related factors that can confound the relationship between LBDs and WBV [43]. Confounders such as job satisfaction, poor social support at work, and job demands should be considered in future studies of farmers, since many studies of LBD have demonstrated their importance [13, 45].

Different study designs contributed to the inconclusiveness of the association between LBDs and WBV. The majority of the studies were non-cohort studies, with six being cross-sectional [29-31, 33, 34, 39] and three case-control [32, 38, 40]. However, only two cross-sectional [30, 33], and one case-control [40] study found association between WBV and LBDs. The cross-sectional design is quick, less expensive, less time intensive, requires no follow-up, and primarily is used in ascertaining prevalence [46] and measures of association, but it is known to have a limitation in assessing temporality of cause and effect relationships [47]. The association between WBV and LBDs found by the cross sectional studies [30, 33] could be due to potential measurement or information biases, as the design has the limitation of not being able to show causality [48]. The authors concluded that “no causal conclusion could be drawn” from this study [30], in part due to misclassification of the outcome [33]. Thus, according to Gomez et al. the outcomes (aches, pain, or discomfort) “are very general and make no reference to the etiology, duration, or severity” [33] of LBDs. This may affect the correct determination of the



outcome status. The case-control design also does not rely on long follow-ups to assess cause and effect relation, which makes it relatively quick and cheap to perform; however, it has issues with biased results [49]. Threats to validity include selection bias related to factors such as “differential surveillance, diagnosis, or referral of individuals into the study” [50] and/or recall bias because the time participants were recruited into the study, both outcome and exposure had already happened [50]. Although, an association can be found using case control, the use of a more rigorous design can help elucidate the association further [51]. Retrospective cohort designs are “less expensive to perform” and “require less time to assemble the cohort” [52] than prospective cohort design. However, its ability to provide stronger evidence on causality is low as compared with studies from prospective cohort design [53]. In addition, data collected retrospectively may be subject to various disadvantages which include “limited control over the data” since the data had been collected already [47], incompleteness of the data, and between subject measurement may be inaccurate [47, 54]. Three retrospective cohort studies were included in the present review [35-37]: a) study 1 found a positive association between WBV and LBDs [35]; b) study 2 also found a positive association between LBDs and WBV measured in vibration dose [36], but showed a mixed association between LBDs and WBV measured in duration of exposure (years) and equivalent vibration magnitude ( $a_{eq}$  m/s<sup>2</sup>) depending on exposure categories [36]; and c) study 3 found no association [37]. Although the evidence of the present review findings suggest that studies which used retrospective cohort designs were more likely to find an effect, however, the use of prospective cohort can help clarify this further. For an appropriate conclusive statement on the association between WBV and LBDs, more cohort prospective cohort studies are needed.

The point estimates of the ORs varied approximately between 1 and 3; irrespective of the sample size and confidence intervals. Odds ratios less than 3 interpreted as Cohen's index of effect size, can be considered to be small [55]. Confidence intervals indicate the range of plausible values for the odds ratios and also give a measure of precision of the point estimates [56]; large confidence intervals suggest that the study group is highly dispersed [57], and sample size is insufficient for the analysis performed [56]. Some studies revealed wide confidence intervals CI 0.52-21.1 [39] and CI 1.21-11 [36] with sample size N=759 and N=577, respectively. Correspondingly, studies with larger sample sizes generally revealed narrower confidence intervals. Bernard et al, with sample size N=3947, found a confidence interval (CI 1.15-1.80) [30]; Gomez et al, with N=1706, found confidence interval (CI 1.20-1.89) [33]; and Bovenzi et al, with N=1155, found confidence interval (CI 1.48-3.74) [40]. Also, confidence interval size depends on the choice of the level of confidence [57]. The present review found nine studies which used confidence level of 95% [29-34, 38-40], and two studies used confidence level of 90% [36, 37]. Although unusual confidence intervals can be converted into more conventional 95% confidence intervals, one study did not specify [35]. This further suggests how difficult it is to compare results across studies. For example, Boshuizen et al notes that firm conclusion cannot be made on the association between WBV and LBD-related disability due to the small sample size of N= 499 in that study [37]. Although two of the studies that did not find an association between WBV and LBDs had relatively large sample sizes (N> 1000) [32, 34], this may not be enough as larger sample sizes will be needed to detect smaller difference [58], and also to handle measurement errors [58].

Despite these facts, a blanket statement cannot be made on under-power of studies which found no association.

Exposure assessment methods used by studies could also play a major role in determining a practical sample size. For instance, Milosavljevic et al.'s study [29], with sample size N=130, used a direct exposure assessment of WBV. Due to time and expense, direct measurement is difficult to apply to a large sample size when compared to self-report [59-61]. In addition, three [30, 33, 40] of the four studies that used large sample sizes found an association between WBV and LBDs; generally, an effect was found with larger studies. Therefore, the variability in the ranges of confidence intervals in the present review, (i.e., some are narrow and others wide, see figure 3) can be attributed in part to the diversity in sample size by studies and level of confidence.

The definition of LBDs varied across studies, a long -acknowledged issue in LBDs research despite efforts to standardize [62-64]. Studies used a range of tools to capture LBDs status, including : the Standard Nordic Questionnaire [30, 33, 34, 40]; other questionnaires [29, 36, 37, 39]; clinical diagnosis obtained from examination [32, 35, 38] and one did not specify [31]. Most notable differences were the prevalence of LBDs periods found in non-cohort studies. Six studies defined LBDs as any pain in the lower back in a twelve month period [30-34, 38], one in terms of "several weeks or longer" [36], and one in 6 weeks or more [39]. Several studies gave range of time periods: two weeks, 12 months, and lifetime [35]; 7 days and 12 months [29]; 12 months and 1 month [40]; and one was not specified [37].

Studies showed considerable heterogeneity in terms of statistical strategy, LBD definition, types of commodity produced, and type of design, making comparisons and synthesis difficult. This observation has also been made by Osborne et al in a review of musculoskeletal disorders among farmers: “one consequence of the study heterogeneity is results that are not generalizable” [65].

### 2.5.2 Exposure assessment

Overall, the precision of exposure assessment was low. A limited number of studies that used direct exposure assessment were found in the present review; however, they suggest a trend of no relationship. “Direct technical methods offer more reliable and valid data than self-reports”[59]. However, moderate cost and the ability to sample large numbers of subjects have popularized the use of self-reports [59]. The range of exposure assessments methodologies among included studies was notable. Some studies used only direct measurement [29, 37], some used a combination of direct and self-report [35, 40], and others only self-report exposure assessment [30-34, 36, 38, 39]. Studies which used only direct measurements found no association between WBV and LBDs; this could be due to in part smaller sample sizes used by these studies. The dimension of exposure, described by Winkle and Mathiassen [59] as level, duration, or frequency of exposure, also varied by study. Six of the studies measured exposure in duration [31-34, 38, 39], two used both duration and vibration dose value [37, 40], one used frequency of exposure [35], one only vibration dose value (VDV) [29], one included three dimensions (vibration magnitude, duration, and vibration dose value [36]), and one did not specify [30]. This may also contribute to the difference between studies, as machines with certain vibration frequencies might produce more effect than others. Allan et al. note that

vibration dose values (VDV) measures cumulative vibration dose and is much more dependent on vibration magnitude than duration [66]. The VDV is based on a “fourth power time dependency to accumulate vibration severity over the exposure period from the shortest possible shock to a full day of vibration”[67]. Unlike duration, VDV can measure the “severity of transients, shocks, and repeated shock motions”[68], hence results might represent different aspects of injury mechanism. Boshuizen et al. note that the trend of increasing prevalence with increasing vibration exposure becomes weaker for all types of back pain when duration of exposure is used instead of vibration dose to form exposure categories [36]. This perhaps resulted in most included studies not finding a positive association between WBV and LBDs, as most studies used exposure categories based on duration. Studies also used different approaches in summarizing exposure; some used categories [30, 32, 33, 35-40], and others a continuous variable [29, 34].

Low-quality exposure assessments used by studies could hinder identification of the association between LBDs and WBD. The majority of the studies reviewed used self-report exposure assessments. A review by Bernard et al. [69] notes that self-report exposure assessments used by studies likely obscure association between WBV and back pain [69]. Interestingly, the present review found no association between WBV and LBDs in 2 of studies that used direct exposure assessment [29, 37]. Direct exposure measurements have been found to “provide more reliable data than those based on observations or subjective judgements”[70]. This suggests that future research should focus more on direct exposure assessment methods. However, while direct exposure assessment produces accurate data, its expense limits its use in obtaining large sample sizes. Besides self-report being easy and inexpensive to use [70], it has

low reliability and validity hence not a preferred choice for ergonomics [71]. On the contrary, studies that used a combination of direct and self-report found positive associations between WBV and LBDs [36, 40]. These used a task exposure matrix or ‘vehicle exposure matrix’ to combine directly measured vibration and self-reported time on each vehicle to develop a cumulative dose model. In addition, the choice of an exposure assessment method may also depend on the study design. For example, retrospective exposure assessment can only be done through self-report, since it is not possible to either observe or apply direct measures.

### **2.5.3 Agriculture: a diverse industrial setting**

The present review found considerable diversity in the samples in terms of commodity produced, region, and farmer characteristics (sex, social-demographic and employment status). In terms of commodity, several farms types were included: 5 studies concentrated on farmers who were involved in mixed farming commodities (e.g. beef, hay, mushroom, poultry) [31-34, 38], only one focused on animal products (e.g. dairy, beef, sheep) [29], and three focused on crop production (e.g. melon, grapes, apple) [30, 39, 40]. Three studies’ commodities were not specified, but may also represent mixed commodities [35-37]. The 12 studies also span across 4 of the continents. This includes 7 from Europe [30, 32, 34, 36-38, 40], 3 from North America [31, 33, 39], 1 from Asia [35], and 1 from Australia [29]. The single country that dominated in this review was the Netherlands with 4 studies. The predominance of studies from developed and industrialised nations was not surprising as their farming is done “commercially on a large-scale, highly mechanised, characterised by abundance of engine-powered equipment and with human input being predominantly that of a controller” [72]. In contrast, farming in developing countries is mostly done on subsistence bases and characterised by “limited mechanical power”

used for tasks such as “land preparation, crop care, processing”, and manual, labour-intensive [72]. The diversity in region of farmers may also explain the diversity in commodities produced. A variety of commodities were named, but only within the developed world; other studies did not describe the commodities despite commodity likely having an impact on the nature and range of machinery used. Task, machines, and seasonality differed a lot between studies and, as stated by Burström et al.’s “those who in one study were considered low-exposure might in another study be regarded as highly exposed” [73]. The diversity in the industry explains some of the difficulties involved in making a firm conclusion of the association between WBV and LBDs.

There is evidence that personal factors like age, sex [74], and ethnicity [75] are important in the development of LBDs. Information on age has been found to be important when examining the relationship between WBV and LBDs as it can confound the relationship [43]. In addition, sex has been found to be an important factor to control for when investigating the association between LBDs and WBV [76]. The farmers themselves were also varied; in terms of sex, five studies were on both males and females [29, 30, 33, 34, 39], and four studies were on only male farmers [32, 36, 37, 40] and 1 on only female [31]. The two studies that did not specify sex probably did not control for it as a variable which might have influence the relationship between LBDs and WBV. Also, apart from 2 studies that did not specify sex distribution, the studies showed a higher percentage of males than females. Some studies reported age range [31, 33, 39, 40], and others did not [29, 30, 32, 34-38]. Studies which did not provide any information on age probably did not account for the effect of age on the relationship between LBDs and WBV. In terms of employment status, studies from Europe identified farmers to be

self-employed and farm workers [30, 32, 34, 36] while those in North America were migrant, seasonal farm workers, and farm operators [33, 39]. Farmer participants from Australia were self-employed and rural workers [29]. The 3 studies from North America described the participants as ‘whites’, ‘Hispanics’, and ‘Latinos’ [31, 33, 39]. This demonstrates the representativeness of studies included in the present review.

#### 2.5.4 Quality Assessments

In addition to the STROBE criteria [27], a tool developed by Hoy et al. [26] was employed to examine study in terms of risk of bias. Quality assessment of the studies showed some consistent strong and weak points in the included articles. For example, a risk question which was found to be always ‘yes’ across all studies was on “Direct Data Collection”. Questions that had 5 studies were rated “no” on “Random sampling”, and “Non-Response Bias”. Non-response bias just like all other study biases can pose a severe threat to validity of interpretation and generalization of results [77, 78]. The “unique strength of randomization is that if successfully accomplished, it prevents selection bias” [79]. This suggests that non-randomization may introduce a bias which can affect the validity of interpretation and generalization of results. Other criteria that were harder for studies to meet include: “Appropriate Length of Prevalence Period”, and “Appropriate Numerator and Denominator”. In terms of studies with greater risk, some tended to be mixed association depending on the exposure categories, and one positive association. To improve the quality of studies, future research should perform and report appropriate numerators and denominators as well as appropriate sampling strategies.



### 2.5.5 Comparison to other industries

Since agriculture represents a unique occupational setting with respect to the level, duration, and frequency of WBV exposures, it seems likely that the relationship between WBV and LBDs is unique to this industry. The present review focused on selected population of farmers as a high-risk group [5], unique in that they tend to retire at a later age, work long hours [21] and start work younger than in other occupations [19, 20]. The results of the present review, however, are consistent with previous reviews that were not restricted to one industry in that firm conclusions cannot be drawn.

Lings and Yde [80] literature review on WBV and LBDs which included a mixed occupational group found no definitive evidence to support the association between WBV and LBP. The authors suggested that “good prospective studies with repeated measurement of exposures and clear (outcome) definition” [80] are needed to draw firm conclusion. Similarly, Chambers’ review on workplace WBV and LBP found insufficient evidence to establish that WBV was causally associated with LBP [81]. The authors attributed the reason to temporal limitations of cross-sectional studies [81]. Waters et al. review on heavy equipment vehicles and LBDs also concluded that their review could not provide definitive evidence on the causal association between WBV and LBD and strongly suggested the deployment of prospective cohort studies to investigate this association as well as studies to investigate the biological plausibility of this association [44]. Bovenzi et al.’s review on WBV and LBP also concluded that there is not sufficient evidence of a clear relationship between WBV and LBDs, and the authors similarly attributed the insufficient evidence to limitations of cross-sectional design [82]. Contrarily, Burström et al.’s more recent 2014 review on WBV and LBDs found that there is “scientific

evidence that exposure to WBV increases the risk of LBD” [73]. The authors suggest that their review found an association when others did not because more recent published articles used in their review, and also the “use of more stringent criteria for inclusion had led to a slightly higher risk of LBDs due to WBV exposure compared with previous reviews” [73]. Although Burström et al.’s review found an association between WBV and LBDs, they still note that a limited number of prospective studies have been published on WBV and LBDs [73], which suggests that more prospective studies are still needed.

As in the farming-specific studies in present review, several reviews on all industries state that there is insufficient evidence to decisively support a causal relationship. However, the relationship cannot be rejected, and the proposed mechanism has high biological plausibility [83]. As in the present reviews, prior reviews agree that the primary limitation stems from a lack of published prospective studies with high quality exposure measurement approaches, and provide a direction for future research.

#### **2.5.6 Strengths and limitations of the review**

This review represents first time such a study on association between WBV and LBDs has been done in the high-risk group select population of farmers [5]. It also provided detailed information on exposure assessment cut-offs and captures the complex relationship between WBV and LBDs in a WBV exposed industry. Additionally, the search for studies was done comprehensively and screened rigorously to meet the inclusion criteria as described in an *a priori* registered protocol [22]. In terms of the risk of bias, the review adapted standard questions from published tools found to be reliable [26], as well as academic checklists for

observational studies [27]. However, the present review also has some limitations. Although we assessed quality and risk of bias, due to the low number of articles we did not eliminate studies based on quality as did Burström et al. [73]. Heterogeneity in the measures of association, exposure assessment, and the commodity produced limited the present review from pursuing meta-analysis.

## 2.6 Conclusion

Within the **population** of adult farmers globally, the body of evidence suggests that the relationship of **WBV exposure** to the **outcome** of LBD is unclear. This review showed that findings are inconclusive; four studies showed no association between WBV and LBDs, four studies showed a positive association between WBV and LBDs. In addition, four studies showed mixed association between LBDs and WBV depending on exposure categories. Considerable heterogeneity in terms of inferential test, LBDs definition, type of commodity produced, and type of design, makes comparisons and synthesis difficult. Although retrospective cohort studies tended to show a relationship, future studies with a prospective cohort design can help clarify this association further. Future research should also focus on LBDs definition standardization and more consistent WBV exposure measures. Ultimately, a better understanding of the association of WBV and LBDs will assist in developing strategies to prevent and reduce pain, loss of productivity, temporary or permanent disabilities in farmers.

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## 2.7 References

1. De Beeck, R.O. and V. Hermans, *work-related low back disorders*. Brussels: Institute for Occupational Safety and Health, 2000.
2. WHO, *Drugs, Essential Policy, Medicines. Priority Medicines for Europe and the World: A Public Health Approach to Innovation*. 2004: World Health Organization.
3. Maetzel, A. and L. Li, *The economic burden of low back pain: a review of studies published between 1996 and 2001*. Best Practice & Research Clinical Rheumatology, 2002. **16**(1): p. 23-30.
4. Holmberg, S., et al., *Musculoskeletal symptoms among farmers and non-farmers: a population-based study*. International journal of occupational and environmental health, 2002. **8**(4): p. 339-345.
5. Driscoll, T., et al., *The global burden of occupationally related low back pain: estimates from the Global Burden of Disease 2010 study*. Annals of the rheumatic diseases, 2014. **73**(6): p. 975-981.
6. Zhao, W., *Preventing Low Back Pain in Agriculture. Rutgers NJAES Cooperative Extension*. <https://njaes.rutgers.edu/pubs/publication.asp?pid=FS661>. 1992.
7. Borenstein, D., "Low Back Pain," in Barker LR, Burton JR (eds):. *Principles of Ambulatory Medicine*. 1991.
8. Goglia, V., et al., *Hand-transmitted vibration from the steering wheel to drivers of a small four-wheel drive tractor*. Applied ergonomics, 2003. **34**(1): p. 45-49.
9. Hostens, I. and H. Ramon, *Descriptive analysis of combine cabin vibrations and their effect on the human body*. Journal of sound and vibration, 2003. **266**(3): p. 453-464.
10. Manchikanti, L., *Epidemiology of low back pain*. Pain physician, 2000. **3**(2): p. 167-192.
11. Chen, J.-C., et al., *Using" exposure prediction rules" for exposure assessment: an example on whole-body vibration in taxi drivers*. Epidemiology, 2004. **15**(3): p. 293-299.
12. Varghese, M., et al. *A biomechanical and MRI analysis of back pain among drivers exposed to tractor vibrations*. in *2000 International Conference on the Biomechanics of Impact*. 2001. International Research Council on the Biomechanics of Impact BRON Cedex,, France.

13. Bovenzi, M., et al., *An epidemiological study of low back pain in professional drivers*. Journal of Sound and Vibration, 2006. **298**(3): p. 514-539.
14. Putz-Anderson, V., et al., *Musculoskeletal disorders and workplace factors*. A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati: National Institute for Occupational Safety and Health, 1997.
15. Palmer, K.T., et al., *Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey*. Occupational and Environmental Medicine, 2000. **57**(4): p. 229-236.
16. Palmer, K.T., et al., *Case-control study of low-back pain referred for magnetic resonance imaging, with special focus on whole-body vibration*. Scand J Work Environ Health, 2008. **34**(5): p. 364-373.
17. Lee, W.J., E.S. Cha, and E.K. Moon, *Disease prevalence and mortality among agricultural workers in Korea*. Journal of Korean medical science, 2010. **25**(Suppl): p. S112-S118.
18. Griffin, P.J., *Safety and Health in Agriculture*. "Farming - a hazardous occupation – how to improve health & safety?".  
<http://www.europarl.europa.eu/document/activities/cont/201303/20130321ATT63633/20130321ATT63633EN.pdf>.
19. United States Department of Agriculture, *Technical bulletins*.  
<https://books.google.ca/books?id=eywaJmIWRecC>. 1946(876-900).
20. OCCUPATIONAL HEALTH DISPARITIES. Inputs: Occupational Safety and Health Risks.  
<http://www.cdc.gov/niosh/programs/ohd/risks.html>.
21. Australian Bureau of Statistics. *Australian farming and farmers*. , in *Australian Social Trends*. 2012.
22. PROSPERO (CRD42014013247). Centre for Reviews and Dissemination website.
23. Davies, K.S., *Formulating the evidence based practice question: a review of the frameworks*. Evidence Based Library and Information Practice, 2011. **6**(2): p. 75-80.

24. Huang, X., J. Lin, and D. Demner-Fushman. *Evaluation of PICO as a knowledge representation for clinical questions*. in *AMIA annual symposium proceedings*. 2006. American Medical Informatics Association.
25. Lichtenstein, A.H., E.A. Yetley, and J. Lau, *Application of Systematic Review Methodology to the Field of Nutrition: Nutritional Research Series, Vol. 1*. 2009.
26. Hoy, D., et al., *Assessing risk of bias in prevalence studies: modification of an existing tool and evidence of interrater agreement*. *Journal of clinical epidemiology*, 2012. **65**(9): p. 934-939.
27. Von Elm, E., et al., *The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies*. *Preventive medicine*, 2007. **45**(4): p. 247-251.
28. *Forest plot*. Medcalc.org. <https://www.medcalc.org/manual/forestplot.php>. 2015.
29. Milosavljevic, S., et al., *Does daily exposure to whole-body vibration and mechanical shock relate to the prevalence of low back and neck pain in a rural workforce?* *Annals of occupational hygiene*, 2012. **56**(1): p. 10-17.
30. Bernard, C., et al., *Biomechanical and psychosocial work exposures and musculoskeletal symptoms among vineyard workers*. *Journal of occupational health*, 2011. **53**(5): p. 297-311.
31. Hathorn, D.C., et al., *Self-reported back pain among farm women in southeast Louisiana*. *AAOHN journal*, 2009. **57**(6): p. 232-238.
32. Hartman, E., et al., *Risk factors for sick leave due to musculoskeletal disorders among self-employed Dutch farmers: A case-control study*. *American journal of industrial medicine*, 2006. **49**(3): p. 204-214.
33. Gomez, M., et al., *An analysis of self-reported joint pain among New York farmers*. *Journal of agricultural safety and health*, 2003. **9**(2): p. 143-157.
34. Toren, A., et al., *Tractor-driving hours and their relation to self-reported low-back and hip symptoms*. *Applied Ergonomics*, 2002. **33**(2): p. 139-146.
35. Kumar, A., et al., *Effect of whole-body vibration on the low back: a study of tractor-driving farmers in north India*. *Spine*, 1999. **24**(23): p. 2506.

36. Boshuizen, H.C., P.M. Bongers, and C.T. Hulshof, *Self-reported back pain in tractor drivers exposed to whole-body vibration*. International archives of occupational and environmental health, 1990. **62**(2): p. 109-115.
37. Boshuizen, H.C., C.T. Hulshof, and P.M. Bongers, *Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration*. International archives of occupational and environmental health, 1990. **62**(2): p. 117-122.
38. Hartman, E., et al., *Exposure to physical risk factors in Dutch agriculture: Effect on sick leave due to musculoskeletal disorders*. International journal of industrial ergonomics, 2005. **35**(11): p. 1031-1045.
39. Xiao, H., et al., *Agricultural work and chronic musculoskeletal pain among Latino farm workers: the MICASA study*. American journal of industrial medicine, 2013. **56**(2): p. 216-225.
40. Bovenzi, M. and A. Betta, *Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress*. Applied ergonomics, 1994. **25**(4): p. 231-241.
41. Hathorn, D.C., et al., *Self-reported back pain among farm women in southeast Louisiana*. AAOHN journal: official journal of the American Association of Occupational Health Nurses, 2009. **57**(6): p. 232-238.
42. Cummings, P., *The relative merits of risk ratios and odds ratios*. Archives of pediatrics & adolescent medicine, 2009. **163**(5): p. 438-445.
43. Teschke, K., et al., *Whole Body Vibration and Back Disorders Among Motor Vehicle Drivers and Heavy Equipment Operators A Review of the Scientific Evidence*. Occupational Hygiene, 1999. **6**: p. 123.
44. Waters, T., et al., *The impact of operating heavy equipment vehicles on lower back disorders*. Ergonomics, 2008. **51**(5): p. 602-636.
45. Clays, E., et al., *The impact of psychosocial factors on low back pain: longitudinal results from the Belstress study*. Spine, 2007. **32**(2): p. 262-268.
46. Mann, C., *Observational research methods. Research design II: cohort, cross sectional, and case-control studies*. Emergency Medicine Journal, 2003. **20**(1): p. 54-60.

47. Song, J.W. and K.C. Chung, *Observational studies: cohort and case-control studies*. Plastic and reconstructive surgery, 2010. **126**(6): p. 2234.
48. Bailey, L., et al., *Introduction to Epidemiology*. 2005.
49. Fletcher, R., S. Fletcher, and E. Wagner, *Clinical epidemiology, the essentials*, 1996. Victor Graphics Inc., Baltimore, MD.
50. Hennekens, C.H., J.E. Buring, and S.L. Mayrent, *Epidemiology in Medicine*. 1987: Little, Brown.
51. Justin Besen, S.D.G., *A Critical Evaluation of Clinical Research Study Designs*. Journal of Investigative Dermatology, 2014. **134**(18).
52. Ho, P.M., P.N. Peterson, and F.A. Masoudi, *Evaluating the Evidence Is There a Rigid Hierarchy?* Circulation, 2008. **118**(16): p. 1675-1684.
53. Wassertheil-Smoller, S. and J. Smoller, *Biostatistics and epidemiology: a primer for health and biomedical professionals*. 2015: Springer.
54. Hulley SB, C.S., Browner WS, et al., *Designing Clinical Research: An Epidemiologic Approach*. 2nd Ed ed. 2001, Philadelphia: Lippincott Williams & Wilkins.
55. Chen, H., P. Cohen, and S. Chen, *How big is a big odds ratio? Interpreting the magnitudes of odds ratios in epidemiological studies*. Communications in Statistics—Simulation and Computation®, 2010. **39**(4): p. 860-864.
56. Katz, M., *Multivariable analysis: a practical guide for clinicians*. 1999. NY: Cambridge University Press.
57. Du Prel J-B, Hommel G, Röhrig B, Blettner M. Confidence Interval or P-Value?: Part 4 of a Series on Evaluation of Scientific Publications. *Deutsches Ärzteblatt International* 2009;106(19):335-339. doi:10.3238/arztebl.2009.0335.  
<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2689604/>.
58. David Feldman, R.M., Dorothy Nelson, Clifford J. Rosen, *Osteoporosis (Third Edition)*. Vol. Volume 1. 2008: Elsevier.
59. Winkel, J. and S.E. Mathiassen, *Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations*. Ergonomics, 1994. **37**(6): p. 979-988.



60. Trask, C., et al., *Measuring low back injury risk factors in challenging work environments: an evaluation of cost and feasibility*. American journal of industrial medicine, 2007. **50**(9): p. 687-696.
61. Trask, C., et al., *Data collection costs in industrial environments for three occupational posture exposure assessment methods*. BMC medical research methodology, 2012. **12**(1): p. 89.
62. Deyo, R.A., et al., *Report of the NIH Task Force on research standards for chronic low back pain*. Pain Medicine, 2014. **15**(8): p. 1249-1267.
63. Stanton, T.R., et al., *Definitions of recurrence of an episode of low back pain: a systematic review*. Spine, 2009. **34**(9): p. E316-E322.
64. Dionne, C.E., et al., *A consensus approach toward the standardization of back pain definitions for use in prevalence studies*. Spine, 2008. **33**(1): p. 95-103.
65. Osborne, A., et al., *Risk factors for musculoskeletal disorders among farm owners and farm workers: A systematic review*. American journal of industrial medicine, 2012. **55**(4): p. 376-389.
66. Allan, M., D. Duschlbauer, and M. Harrison, *Implications of updating the vibration assessment methodology of bs6472 from the 1992 to the revised 2008 version*. Acoustics Australia, 2010. **38**(2): p. 95-98.
67. Fahy, F. and J. Walker, *Fundamentals of noise and vibration*. 1998: CRC Press.
68. Bhattacharya, A. and J.D. McGlothlin, *Occupational ergonomics: theory and applications*. 1996: CRC Press.
69. Bernard, B., V. Putz-Anderson, and S. Burt, *A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*. Cincinnati: Centers for Disease Control and Prevention National Institute for Occupational Safety and Health publication, 1997: p. 97-141.
70. David, G., *Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders*. Occupational medicine, 2005. **55**(3): p. 190-199.

71. Li, G. and P. Buckle, *Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods*. Ergonomics, 1999. **42**(5): p. 674-695.
72. Scott, P.A., J. Charteris, and R. Bridger, *Global Ergonomics*. 1998: Elsevier.
73. Burström, L., T. Nilsson, and J. Wahlström, *Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis*. International archives of occupational and environmental health, 2014: p. 1-16.
74. Waterman, B.R., P.J. Belmont, and A.J. Schoenfeld, *Low back pain in the United States: incidence and risk factors for presentation in the emergency setting*. The Spine Journal, 2012. **12**(1): p. 63-70.
75. Harms, M.C., C.E. Peers, and D. Chase, *Low back pain: what determines functional outcome at six months? An observational study*. BMC musculoskeletal disorders, 2010. **11**(1): p. 236.
76. Xu, Y., E. Bach, and E. Orhede, *Work environment and low back pain: the influence of occupational activities*. Occupational and environmental medicine, 1997. **54**(10): p. 741-745.
77. Leadbetter, S., et al., *Peer Reviewed: Recruiting Women for a Study on Perceived Risk of Cancer: Influence of Survey Topic Salience and Early Versus Late Response*. Preventing chronic disease, 2013. **10**.
78. Mazor, K.M., et al., *A demonstration of the impact of response bias on the results of patient satisfaction surveys*. Health services research, 2002. **37**(5): p. 1403-1417.
79. Higgins, J., *Green S. Cochrane handbook for systematic reviews of interventions Version 5.1. 0 [updated March 2011]. The Cochrane Collaboration, 2011*. www.cochrane-handbook.org, 2014.
80. Lings, S. and C. Leboeuf-Yde, *Whole-body vibration and low back pain: A systematic, critical review of the epidemiological literature 1992–1999*. International archives of occupational and environmental health, 2000. **73**(5): p. 290-297.

81. WorkSafeBC, *WorkSafeBC Evidence-Based Practice Group 2008*.  
[http://www.worksafebc.com/health\\_care\\_providers/Assets/PDF/whole\\_body\\_vibration\\_low\\_back\\_pain.pdf](http://www.worksafebc.com/health_care_providers/Assets/PDF/whole_body_vibration_low_back_pain.pdf).
82. Bovenzi, M. and C. Hulshof, *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, 1999. **72**(6): p. 351-365.
83. Viruet, H.B., et al., *Effect of forklift operation on lower back pain: An evidence-based approach*. Human Factors and Ergonomics in Manufacturing & Service Industries, 2008. **18**(2): p. 125-151.

## Chapter 3: Methodology

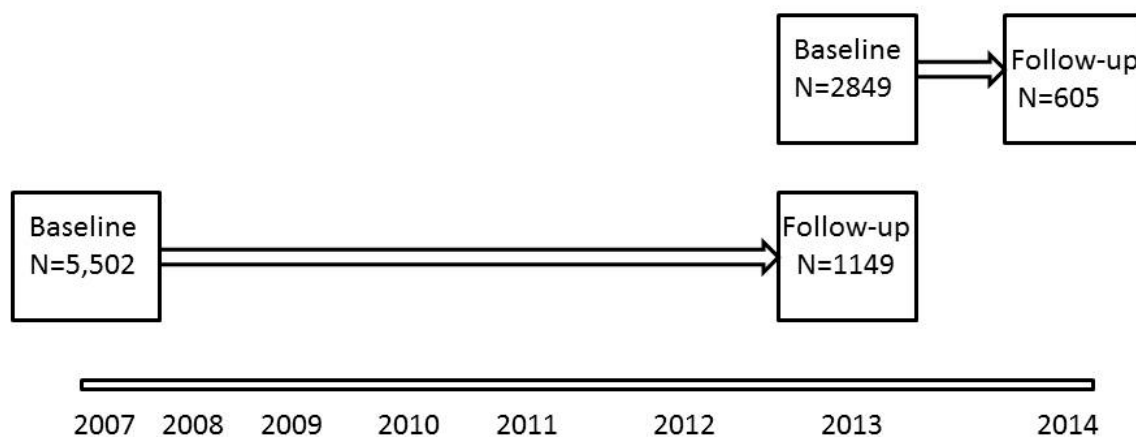
The methods used by studies may influence both the interpretation of results and the outcomes. Hence, this chapter describes the methods used by the Saskatchewan Farm Injury Cohort (SFIC), as well as the statistical approaches and analysis methods used in manuscript 2 (chapter 4).

### 3.1 Saskatchewan Farm Injury Cohort Study Methods and Measures

The data used for this chapter and manuscript 2 (association between whole body vibration and low back disorder in farmers: a prospective cohort study) comes from a large prospective cohort study: the Saskatchewan Farm Injury Cohort (SFIC) Study Phase I and Phase II. The SFIC project aims to “(1) examine associations between individual farm exposures and the occurrence of various types of farm injury in the province of Saskatchewan, Canada, and (2) assess the importance of the contextual factors (physical, socio-economic, and cultural) as potential moderators of association between individual farm exposures and the occurrence of injury” [1, 2]. The target population for the SFIC was farm people in Saskatchewan. Phase 1 started in 2007 involving distribution of a postal questionnaire [1]. Phase 1 baseline data was collected from 5,492 farm people on 2,390 Saskatchewan farms [2] in fifty rural municipalities [1]. Follow-up surveys were distributed every six months for two years and reported farm injury cases with add-on text narratives of the circumstances surrounding each injury event were collected [1]. Similarly, Phase II started in 2013 with baseline data collected from 2,849 farmer participants on 1216 Saskatchewan farms [3].

Although information on many farm exposures, hazards, and potential confounders were collected, the primary exposure of interest for this thesis was operation of vibrating equipment, machinery, or vehicles on the farm. Unique among prior farm surveys, the SFIC exposure data captured information on several farm vehicles or machineries including: tractors, ATVs, and combines.

Follow-up data on musculoskeletal symptoms, the primary outcome of the dependent variable of interest to this thesis, were collected in 2013 from a subset of Phase I participants who remained in the study for the 6 intervening years: 1149 of farmer participants on 582 farms. In addition, a one-year follow-up data on musculoskeletal symptoms were collected in 2014 from 605 of farmer participants on 605 farms (see figure 4).



**Figure 4: Baseline and follow-up sample sizes for the six years and one year time intervals**

Questions on musculoskeletal symptoms used by the SFIC project were adapted from the Standardised Nordic Questionnaire (SNQ) (see figure 5) for the analysis of musculoskeletal symptoms[4]. Farmer participants were asked to answer “yes” or “no” to two questions asked for 9 body parts (neck, shoulder, elbows, wrist/hands, upper back, low back, hips/thighs, knees,

and ankles/feet): 1) trouble (ache, pain, discomfort) experienced in the last 12 months, and 2) whether it has prevented them from doing their normal work (at home or away from home) in the last 12 months. The Standardized Nordic Questionnaire (SNQ) has been found to be acceptable tool for collecting self-reported prevalence data. The SNQ has been tested in terms of validity by comparing clinical diagnosis [4], and in terms of its reliability [4]. The test-retest method used to assessed the reliability of the SNQ comprising samples 19-29 workers of three separate studies ranged from 0 to 23% disagreement while its validity was tested by comparing clinical history of two separate studies with samples 19 and 20 workers varied between 0-20% disagreement [4, 5]. In addition, the reliability and validity of the SNQ is considered acceptable for use in workplace ergonomics [5]. Previous study on the sensitivity and specificity of the SNQ using clinical examination as the reference method, found the sensitivity in a range of situations ranging from 82.3% to 100% and specificity from 51.1% to 82.4% [6].



	Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in:			Have you at any time in the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?				
	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
Neck	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
One or both shoulders	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
One or both elbows	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
One or both Hands	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
Upper Back	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
Lower Back	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
One or both hips/thighs	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
One or both knees	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
One or both ankles	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>

**Figure 5: Adapted Standardized Nordic Questionnaire (Kuorinka et al. 1987)**

Since the effects of WBV may accumulate over several years, this thesis intended to investigate the effect of follow-up duration on the relationship between WBV and LBD. Therefore, the SFIC data collected were structured as two follow-up periods: 6-years (2007-2013) and 1-year (2013-2014). Besides the different follow-up durations, the Phase II baseline (i.e. 1-year follow-up) captured several additional potential confounding variables not included in the 6-year follow-up.

## **3.2 Statistical analysis approaches: reviewing the options**

### **3.2.1 Introduction**

Odds ratio (OR) and relative risk (RR) are common measures of association used in medical-related type of research [7]. However, these measures of association are highly dependent on the structure of the dataset in question. Although ORs are frequently reported [8], Holcomb et al. note that the only way to simplify quantitatively the interpretation of odds ratio is to approximate it to relative risk [7]. For instance, an example by Huck on fatality rates and passengers gender found that the “odds of dying were 10 times greater for male than for females” [9]. Meanwhile the same data used to compute the relative risk was simply interpreted as “male passengers were 2.5 times more likely to die than female passengers” [9]. However, as described below, the approximation of odds ratio to relative risk may not be appropriate under all conditions. Hence this thesis chapter provides the rationale and motivation for using relative risk from Modified Poisson as a measure of association to assess the relationship between WBV and LBD. This section contains a review of the pros and cons of this and alternative statistical analysis approaches such as logistic regression and log-binomial regression.

### 3.2.2 Logistic regression

Logistic regression can simply be explained as a “technique for making predictions when the dependent variable is a dichotomy, and the independent variables are continuous and/or discrete” [10]. Austin and Steyerberg note that the purpose of fitting logistic regression is based on three primary reasons namely: “(a) to determine the independent predictors of a binary outcome; (b) to determine the association between a specific variable and the probability of the occurrence of an outcome after adjusting for a set of other covariates; and finally, (c) to predict the probability of the occurrence of a binary outcome given a specific vector of covariates” [11]. The popularity of logistic regression application in all area of public health research is phenomenal [12]. For instance, a study found that over 30% of published articles in the American Journal of Public Health used logistic regression approach [12]. Despite the popularity of logistic regression and it being a powerful statistical tool [12], Hosmer et al. admonish researchers to use logistic regression with caution [12]. For example, a study found that odds ratio from logistic regression is often misinterpreted by some medical practitioners and researchers, as the only way to simplify quantitatively the interpretation of odds ratio is to approximate it to relative risk [7]. However, previous studies have found that odds ratios from logistic regression is not a useful proxy for relative risk when the prevalence of the response variable is common (i.e. >10%) [13, 14]. Thus, when applying logistic regression to highly prevalent outcome, the converted odds ratio to relative risk overstates the relative risk [15, 16]. For example, Green et al. found logistic regression not to be a suitable choice for their study after realizing that their outcome “computer access” was not rare [17]. Similarly, Skandfer et al. found with a 51% prevalence of low back pain in their study the use of logistic regression for



the estimating the risk was a limitation: “for frequently occurring outcomes, such as LBP, the revealed ORs can overestimate the magnitude of the risks” [18]. These findings from previous studies suggest that in spite of the popularity of logistic regression when it comes to highly prevalent outcomes, other alternative (and more statistically appropriate) approaches must be considered.

### 3.2.3 Log-Binomial regression

Although both log-binomial regression and logistic regression assume binomial distribution of the response variable [16], the log-binomial is based on log function and produces adjusted relative risk, while that of the logistic produces an odds ratio based on the logit function.

McNutt et al. note that the link between the independent variables and the probability of the response variable distinguishes logistic model from log-binomial model [15]. The log-binomial model produces an adjusted relative risk which is unbiased [15], however, Marschner and Gillett observed that it often subject to numerical instability [19]. Numerical instability according to Neumaier means that the “error in the result is considerably greater than one would expect from small errors in the input” [20]. Previous studies have also found that the computed confidence intervals from log-binomial models for adjusted relative risk may be narrower than the true confidence interval [15, 21, 22], leading to a false sense of certainty. Similarly, Williamson et al. observed that log-binomial models are prone to convergence issues [23]. Convergence issues occur if the statistical software fail to solve the equation properly [24] and that the certainty of results from such model cannot be guaranteed. According Katz, convergence issues may arise from reasons such as incorrect coding and “too few outcomes for the number of independent variables” [24] in the model.

### **3.2.4 Modified Poisson regression**

A modified (also called robust) Poisson model is a term coined for log-Poisson regression models with robust variance estimation [25, 26] and it is increasingly being used in outcomes that are highly prevalent [13, 17, 27] to estimate relative risk directly. [28]. Kleinbaum simply defined the robust variance estimators as “an adjustment of the model-based estimators” [29], which provide standard errors that are “robust to specification error” [28]. The chief advantage of the robust variance estimation technique is that “it provides a consistent estimate of the variance even if the working correlation is not correctly specified” [29]. In addition, modified Poisson has been found to estimate relative risk consistently and efficiently [25] and is also not prone to convergence issues as in the case of log-binomial model [26, 30]. Modified Poisson based on Generalized Estimating Equations (GEE) have successfully been applied in studies involving prospective cohort designs [26]. A 2014 publication comparing robust Poisson models and log-binomial models found that “the robust Poisson models are more robust to outliers compared to the log-binomial models when estimating relative risk for common binary outcomes” [13]. In summary, Chen et al. cautioned researchers to be “aware of the limitations when choosing appropriate models to estimate relative risk” [13]. As a whole, the literature favours modified Poisson as the preferred choice for estimating relative risk for frequently occurring outcomes.

### **3.2.5 Generalized estimating equations and working correlation structures**

Generalized estimating equations (GEEs) have been found to be a useful statistical technique for analyzing correlated data [31-33]. Kleinbaum described GEE as a “generalization of quasi-likelihood estimation” [33]. However, Ly et al. note that if an appropriate choice of working

correlation structure is not selected when analyzing with GEE approach, parameter estimates will be inefficient [34]. Hence, this thesis reviewed three different working correlation structures and after considering the results as well as recommendations from literature, the best working correlation structure was selected.

Correlated analysis such as GEE can be performed using several different correlation structures. Commonly considered correlation structures include: independent, stationary m-dependent, exchangeable, first order autoregressive (AR1), and unstructured [33, 35]. The data used in the Saskatchewan farm cohort study was correlated which made the independent correlation structure not applicable in this case. Also, besides the data structure not suitable for the use of the m-dependent structure, previous studies have found that the m-dependent correlation structure are “not biologically plausible” [36]. Therefore, this thesis considered an analysis on exchangeable, AR (1) and unstructured for selecting the best working correlation structure. Ziegler and Vens counselled investigators to consider both biological and statistical reasons when selecting a working correlation structure for their analysis [37], which was the approach taken in the current investigation.

The exchangeable correlation structure assumes that “two responses within a cluster have the same correlation”[33] with off-diagonal elements of the correlation matrix being equal and main diagonal equal one (1) [33]. AR (1) correlation structure assumes that the “correlation between response depends on the interval of time between responses” [33]. For example, Kleinbaum notes that responses collected one month apart are assumed to have a greater correlation than 20 months apart [33]. The unstructured correlation does not pose any

constraints [38]. Westgate notes that the unstructured working correlation “estimates more nuisance correlation parameters than other structures such as AR (1) or exchangeable” [31], hence it has limited use in most studies. Shults et al. also reported that for the parsimony of model to be greatly improved, replacing the unstructured with either AR (1) or exchangeable would help [39]. However, several criteria have been proposed including quasi-likelihood under the independence model criterion (QIC) [40], which is found in most statistical software.

### **3.3 Results and Discussion**

#### **3.3.1 Comparison of exchangeable, unstructured, and AR (1) working correlations**

Findings from this section are based on data from 6-year follow-up, the larger of the two datasets. Results from the two separate models fitted with exchangeable and AR (1) were consistent for all variables considered. However, the unstructured correlation showed different findings for some variables (see table 4). For instance, both the bivariate analysis from the exchangeable and AR (1) working correlation structures showed that ATV operation was not significantly related to LBD based on their P-values 0.059 and 0.094 respectively. However, ‘sex’ was found to be significantly related to LBD based on the bivariate results of both the exchangeable and AR (1) working correlation structures (P-value = 0.002). On the other hand, the unstructured working correlation rather found ‘ATV operation’ to be significantly related to LBD (P-value < 0.001) and ‘sex’ not significantly related to LBD (P-value = 0.648). Also, while ‘combine operation’ was found to be significantly related to LBD based on the bivariate results revealed by both exchangeable and AR (1) working correlation (P-value < 0.001), the unstructured found that ‘combine operation’ was not significantly related to LBD (P-value = 0.146). This suggests that if a P-value = 0.25 was set as screening criteria to screen variables

from the bivariate to the multivariate, then 'sex' based on the unstructured correlation structure would not qualify to be a candidate for the multivariate analysis. Meanwhile, previous studies [41, 42] have shown the importance of sex in relation to LBD; therefore, if not adjusted for, it could potentially affect the results.

In addition, in terms of the multivariate analysis results, a difference was seen in 'tractor operation'. Both the exchangeable and AR (1) working correlation found all categories of 'tractor operation' to be significantly related to LBD, however, the unstructured found no association between 'tractor operation' for 1-150 hrs/yr and 151-400 hrs/yr and LBD; the only negative association was found in 401 hrs/yr and above.

These results support previously published findings that "more nuisance correlation parameters" [31] are estimated by the unstructured correlation [31] and is "unreliable with maximum quasi-likelihood under the independence model criterion (QIC) value" [38]. This leaves two options to be considered for the analysis of chapter 4 /manuscript 2: exchangeable or AR (1). To decide, the QIC proposed by Pan [40] was used. According to Pan, "QIC can also be applied to select a working correlation structure in GEE: one needs to calculate the QIC for various candidate working correlation structures and then pick the one with the smallest QIC" [40]. Based on this criterion, the exchangeable working correlation structure was selected as the plausible working correlation for the thesis analysis as it produced the smallest QIC in all the analyses. Although, Shults suggested that the use of the exchangeable and AR (1) help achieve parsimonious model [39], however, in contrast, this chapter found the unstructured to be more parsimonious. This may be linked to an observation made by Westgate that simpler correlation

structure like the unstructured which does not assume constraints on the correlation structure [38] “may perform better in some settings” without appropriate penalties in place [31]. This is a limitation since the proposed penalty modification made to selection criteria by Westgate [31] has not been incorporated into existing statistical softwares. In addition, besides the unstructured working correlation structure not meeting the QIC criteria for selection, sex as a biological factor was found not to be significant. Meanwhile, this investigation assessed the best working correlation based on both statistical (lowest value of QIC) and biological reasons as recommended by Ziegler and Vens [37].

The use of the AR (1) could have produced consistent estimates for the estimates in the manuscript 2 models, however, in GEE, obtaining efficient estimates may ultimately be preferable to researchers than consistent estimates. According to Hin et al., efficiency in GEE is obtained when the intracluster correlation is parametrically modeled accurately to “reduce potential error in estimation or prediction” [43]. But obtaining efficient estimates have been found by previous studies to depend on the right choice of the working correlation structure for the response variable [36, 44-46], the “cluster sizes”, “covariate distribution” and “regression parameters” [45]. On the other hand, parsimony has been found to be a procedure for estimation which takes into account few parameters [47, 48] and “is to be preferred on the grounds of simplicity of explanation” [47]. In summary, the results from chapter 3 and manuscript 2 based on the exchangeable working correlation are deemed to be efficient estimates.

### 3.4 Conclusion

This chapter showed that based on the QIC criterion, the exchangeable working correlation structure was the appropriate choice for these data. Also, for frequently occurring outcomes, we forward support for the modified Poisson as the appropriate choice for estimating the relative risk.

**Table 4: Comparison of Results from Three Different Working Correlation Structures**

	Six-Year Follow-up											
	Exchangeable				AR (1)				Unstructured			
Variables	Bivariate		Adj Model		Bivariate		Adj Model		Bivariate		Adj Model	
	RR	95% CI	RR	95%CI	RR	95% CI	RR	95% CI	RR	95% CI	RR	95%CI
Age												
<=19 (ref)	1.00				1.00				1.00			
20-39	2.04	1.34-3.11	1.82	1.18-2.80	1.95	1.28-2.96	1.70	1.12-2.60	2.86	1.40-5.86	1.76	1.16-2.66
40-55	2.60	1.75-3.81	2.32	1.55-3.47	2.50	1.70-3.69	2.22	1.50-3.29	2.54	1.31-4.94	2.20	1.50-3.24
56-75	2.50	1.68-3.72	2.22	1.48-3.34	2.44	1.65-3.61	2.14	1.44-3.17	2.92	1.67-5.10	2.12	1.43-3.13
76+	1.17	0.59-2.29	1.03	0.50-2.11	1.12	0.56-2.22	0.96	0.46-2.01	1.21	0.55-2.65	0.99	0.49-1.99
	(P-V< 0.001)				(P-V< 0.001)				(P-V <0.001)			
Sex												
Female (ref)	1.00				1.00				1.00			
Male	1.16	1.05-1.28			1.16	1.05-1.28			0.95	0.78-1.17		
	(P-V <0.002)				(P-V = 0.002)				(P-V = 0.648)			
Education level												
Less than high sch	1.00				1.00				1.00			
Completed high sch	1.20	1.04-1.38			1.16	1.01-1.33			1.23	0.90-1.68		
Completed university	1.22	1.04-1.42			1.18	1.01-1.37			1.09	0.81-1.47		
Inst. Other than above	1.17	0.99-1.38			1.14	0.97-1.34			1.16	0.89-1.50		
	(P-V =0.061)				(P-V = 0.142)				(P-V=0.572)			
Operate tractorh/yr												
None (ref)	1.00				1.00				1.00			
1-150	1.29	1.10-1.51	1.23	1.05-1.44	1.29	1.10-1.51	1.24	1.06-1.45	1.63	1.10-2.41	0.97	0.94-1.00
151-400	1.42	1.22-1.65	1.32	1.14-1.54	1.40	1.21-1.64	1.33	1.14-1.54	1.62	1.06-2.47	0.97	0.94-1.00
401+	1.47	1.27-1.72	1.34	1.15-1.56	1.46	1.25-1.70	1.35	1.16-1.57	2.12	1.42-3.17	0.94	0.91-0.98
	(P-V <0.001)				(P-V < 0.001)				(P-V < 0.001)			
Operate combine h/yr												
None (ref)	1.00				1.00				1.00			
1-60	1.11	0.97-1.28			1.11	0.97-1.27			1.22	0.85-1.76		
61-150	1.25	1.10-1.41			1.25	1.10-1.41			1.05	0.73-1.52		
151+	1.29	1.14-1.45			1.28	1.13-1.45			1.62	1.19-2.22		
	(P-V <0.001)				(P-V < 0.001)				(P-V=0.146)			
Operate ATV day/yr												
None (ref)	1.00				1.00				1.00			
1-20	1.12	0.98-1.28			1.12	0.98-1.27			1.04	0.74-1.47		
21-80	1.10	0.94-1.28			1.09	0.93-1.28			1.15	0.77-1.72		
81+	1.21	1.05-1.40			1.19	1.03-1.38			1.42	0.96-2.09		
	(P-V = 0.059)				(P-V = 0.094)				(P-V <0.001)			

\*P-V = P-value

RR = Relative Risk

CI = Confidence Interval

Adj=Adjusted



### 3.5 References

1. Pickett, W., et al., *Determinants of agricultural injury: a novel application of population health theory*. Injury prevention, 2010. **16**(6): p. 376-382.
2. Pickett, W., et al., *The Saskatchewan farm injury cohort: rationale and methodology*. Public health reports, 2008. **123**(5): p. 567.
3. Pickett, W., et al., *Farmers, mechanized work, and links to obesity*. Preventive medicine, 2015. **70**: p. 59-63.
4. Kuorinka, I., et al., *Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms*. Applied ergonomics, 1987. **18**(3): p. 233-237.
5. Baron, S., T. Hales, and J. Hurrell, *Evaluation of symptom surveys for occupational musculoskeletal disorders*. American journal of industrial medicine, 1996. **29**(6): p. 609-617.
6. Descatha, A., et al., *Validity of Nordic-style questionnaires in the surveillance of upper-limb work-related musculoskeletal disorders*. Scandinavian journal of work, environment & health, 2007. **33**(1): p. 58.
7. Holcomb Jr, W.L., et al., *An odd measure of risk: use and misuse of the odds ratio*. Obstetrics & Gynecology, 2001. **98**(4): p. 685-688.
8. Viera, A.J., *Odds ratios and risk ratios: what's the difference and why does it matter?* Southern medical journal, 2008. **101**(7): p. 730-734.
9. Huck, S.W., *Statistical misconceptions*. 2009: Routledge.
10. *logistic-regression-Scholarly-Peer-review-Journal*. <http://omicsonline.org/logistic-regression-scholarly-peer-review-journal.php>.
11. Austin, P.C. and E.W. Steyerberg, *Interpreting the concordance statistic of a logistic regression model: relation to the variance and odds ratio of a continuous explanatory variable*. BMC medical research methodology, 2012. **12**(1): p. 82.
12. Hosmer, D.W., S. Taber, and S. Lemeshow, *The importance of assessing the fit of logistic regression models: a case study*. American journal of public health, 1991. **81**(12): p. 1630-1635.

13. Chen, W., et al., *Comparison of robustness to outliers between robust poisson models and log-binomial models when estimating relative risks for common binary outcomes: a simulation study*. BMC medical research methodology, 2014. **14**(1): p. 82.
14. Greenland, S., *Interpretation and choice of effect measures in epidemiologic analyses*. American journal of epidemiology, 1987. **125**(5): p. 761-768.
15. McNutt, L.-A., et al., *Estimating the relative risk in cohort studies and clinical trials of common outcomes*. American journal of epidemiology, 2003. **157**(10): p. 940-943.
16. Diaz-Quijano, F.A., *A simple method for estimating relative risk using logistic regression*. BMC medical research methodology, 2012. **12**(1): p. 14.
17. Green, B.B., et al., *Patient ability and willingness to participate in a web-based intervention to improve hypertension control*. Journal of medical Internet research, 2011. **13**(1).
18. Skandfer, M., et al., *Low back pain among mineworkers in relation to driving, cold environment and ergonomics*. Ergonomics, 2014. **57**(10): p. 1541-1548.
19. Marschner, I.C. and A.C. Gillett, *Relative risk regression: reliable and flexible methods for log-binomial models*. Biostatistics, 2012. **13**(1): p. 179-192.
20. Neumaier, A., *Introduction to numerical analysis*. 2001: Cambridge University Press.
21. Daddens, J., M.R. Petersen, and L. Endahl, *Prevalence proportion ratios: estimation and hypothesis testing*. International journal of epidemiology, 1998. **27**(1): p. 91-95.
22. Ma S, W.C., *Estimation of prevalence proportion rates. (Letter)*. Int J Epidemiol 1999;28:175.
23. Williamson, T., M. Eliasziw, and G.H. Fick, *Log-binomial models: exploring failed convergence*. Emerging themes in epidemiology, 2013. **10**(1): p. 14.
24. Katz, M.H., *Multivariable analysis: a practical guide for clinicians* second ed. 2006: Cambridge university press.
25. Zou, G., *A modified poisson regression approach to prospective studies with binary data*. American journal of epidemiology, 2004. **159**(7): p. 702-706.

26. Yelland, L.N., A.B. Salter, and P. Ryan, *Performance of the modified Poisson regression approach for estimating relative risks from clustered prospective data*. American journal of epidemiology, 2011: p. kwr183.
27. Kaufman, J.S. and S. Harper, *Deficiency of the Odds Ratio for Common Outcomes*. American Journal of Psychiatry, 2012. **169**(10): p. 1118-1118.
28. Freedman, D.A., *On the so-called "Huber sandwich estimator" and "robust standard errors"*. The American Statistician, 2006. **60**(4).
29. Kleinbaum, D. and M. Klein, *Logistic Regression: Statistics for Biology and Health*. Retrieved from DOI, 2010. **10**: p. 978-1.
30. Zou, G. and A. Donner, *Extension of the modified Poisson regression model to prospective studies with correlated binary data*. Statistical methods in medical research, 2013. **22**(6): p. 661-670.
31. Westgate, P.M., *Improving the correlation structure selection approach for generalized estimating equations and balanced longitudinal data*. Statistics in medicine, 2014. **33**(13): p. 2222-2237.
32. Hanley, J.A., A. Negassa, and J.E. Forrester, *Statistical analysis of correlated data using generalized estimating equations: an orientation*. American journal of epidemiology, 2003. **157**(4): p. 364-375.
33. Kleibbaum, D. and M. Klein, *Statistics for biology and health: logistic regression. A self-learning text*. Atlanta: Springer Verlag NY, 2002.
34. Hin, L.Y. and Y.G. Wang, *Working-correlation-structure identification in generalized estimating equations*. Statistics in medicine, 2009. **28**(4): p. 642-658.
35. Ghisletta, P. and D. Spini, *An introduction to generalized estimating equations and an application to assess selectivity effects in a longitudinal study on very old individuals*. Journal of Educational and Behavioral Statistics, 2004. **29**(4): p. 421-437.
36. Gosho, M., *Criteria to select a working correlation structure for the generalized estimating equations method in SAS*. Journal of Statistical Software, 57, 2014: p. 1-10.

37. Ziegler A and V. M, "*Generalized Estimating Equations: Notes on the Choice of the Working Correlation Matrix.*". *Methods of Information in Medicine*, 49(5), 421–425., 2010.
38. Önder, H., M. Olfaz, and E. Soydan, *Comparison of working correlation matrices in generalized estimating equations for animal data*. *Anadolu Tarım Bilimleri Dergisi*, 2010. **25**(3): p. 197-201.
39. Shults, J. and J.M. Hilbe, *Quasi-Least Squares Regression*. 2014: CRC Press.
40. Pan, W., *Akaike's information criterion in generalized estimating equations*. *Biometrics*, 2001. **57**(1): p. 120-125.
41. Waterman, B.R., P.J. Belmont, and A.J. Schoenfeld, *Low back pain in the United States: incidence and risk factors for presentation in the emergency setting*. *The Spine Journal*, 2012. **12**(1): p. 63-70.
42. Driscoll, T., et al., *The global burden of occupationally related low back pain: estimates from the Global Burden of Disease 2010 study*. *Annals of the rheumatic diseases*, 2014. **73**(6): p. 975-981.
43. Hin, L.-Y., V.J. Carey, and Y.-G. Wang, *Criteria for Working–Correlation–Structure Selection in GEE*. *The American Statistician*, 2007. **61**(4).
44. Chen, J. and N.A. Lazar, *Selection of working correlation structure in generalized estimating equations via empirical likelihood*. *Journal of Computational and Graphical Statistics*, 2012. **21**(1): p. 18-41.
45. Mancl, L.A. and B.G. Leroux, *Efficiency of regression estimates for clustered data*. *Biometrics*, 1996: p. 500-511.
46. Pan, W. and J.E. Connett, *Selecting the working correlation structure in generalized estimating equations with application to the lung health study*. *Statistica Sinica*, 2002. **12**(2): p. 475-490.
47. Goloboff, P.A., *Parsimony, likelihood, and simplicity*. *Cladistics*, 2003. **19**(2): p. 91-103.
48. Goldman, N., *Maximum likelihood inference of phylogenetic trees, with special reference to a Poisson process model of DNA substitution and to parsimony analyses*. *Systematic Biology*, 1990. **39**(4): p. 345-361.

## Chapter 4: Manuscript 2

### **Association between whole body vibration and low back disorder in farmers: a prospective cohort study**

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#### **Contribution Statement:**

SKE's role was to develop the research questions; merge baseline and follow-up databases and clean the data; conduct the analyses; and interpret and summarize results. SKE led the drafting of the manuscript.

## 4.1 Abstract

**Background:** Farmers, more than other occupations, are at high risk of developing low back disorders. Operators of tractors and other farm machinery such as combines and all terrain vehicles (ATV) can have considerable accumulation of exposure to whole body vibration (WBV). However, the causal relationship between LBDs and WBV is not fully clear; attributed in part to limitations of cross-sectional studies.

**Purpose:** This dual cohort study investigates the association between WBV as measured by annual accumulated use of ATV, combines, and tractor operation; and LBDs among farmers.

**Methods:** The data source was the Saskatchewan Farm Injury Cohort Study. In 2007, baseline data were collected on accumulated yearly tractor, combine, ATV operation, as well as several biopsychosocial covariates thought to be associated with LBDs. Follow-up data on LBDs and related symptoms were collected during 2013 (6 year follow-up) and 2014 (1-year). This resulted in two datasets for each of two cohorts: 1) the first cohort with 1,149 farm people who had been followed for six years, and 2) the second with 605 participants who had been followed for one year. Generalized estimating equation-modified Poisson regressions were performed with low back and hip symptoms as the outcome.

**Results:** The adjusted model in cohort 1 found LBDs to be associated to tractor operation for 1-150 hrs/year (RR=1.23, 95%CI 1.05-1.44), 151-400 hrs/year (RR=1.32, 95%CI 1.14-1.54) and 401+ hrs/year (RR=1.34, 95%CI 1.15-1.56). In addition, tractor operation for 151-400 hrs/year (RR=1.95, 95%CI 1.45-2.62) and 401+ hrs/year (RR=1.79, 95%CI 1.32-2.45) was also found to be related to hip symptoms. Although combine operation  $\geq 61$  hrs/year and ATV operation 81+

days/year was related to LBD in the bivariate analysis in cohort 1, this association did not persist after adjustment for confounders. Due to limited power, no significant bivariate association was found between WBV and either LBDs and hip symptoms in cohort 2.

**Conclusion:** Although duration of tractor operation and older age showed with both LBDs and hip symptoms in farmers in cohort 1, the true prospective cohort 2 found no significant association between WBV and LBDs. Future research involving prospective cohort with larger samples and longer follow ups are needed to investigate this association further.

## 4.2 Introduction

Low back disorders (LBDs) are the most common musculoskeletal disorder found in many occupational settings[1]. Farmers, more than workers in other occupations, are at higher risks for developing low back disorder [2] due to their work frequently incorporating activities with physical exposures that are potentially damaging ergonomically [3, 4]. For example, operators of farm tractors and other kinds of farm machinery such as combines and all terrain vehicles (ATV) can have considerable accumulation of exposure to whole body vibration (WBV) [5].

Boshuizen et al. suggested that the high prevalence of back pain in tractor drivers might be partially attributable to whole body vibration [6]. Cvetanovic et al. noted that among the various negative aspects of driving of agricultural tractors, vibrations are especially harmful; there is even an elevated risk for drivers exposed to vibrations as low as one hour per day [7].

Although there is some evidence for a potentially causal relationship between WBV and LBDs, results of reviews have been mixed; some support the relationship [8-12] and some do not [13-16]. A review by Hulshof et al. found that low back pain was among the most frequently reported adverse effects of WBV and suggested further epidemiologic research is needed particularly among high-risk groups [17]. The nature of an industry, driving task, and vehicle type may impact observed relationships with LBDs. An earlier review by Essien et al. on WBV and LBD in farmers found “considerable heterogeneity in terms of statistical strategy, LBDs definition, type of farm commodity, and study design, makes comparisons, and synthesis as well as firm conclusion on association difficult”[18]. However, the authors noted that higher quality studies including the use of prospective cohort design tended to demonstrate the



presence of causal relationships [18]. This highlights earlier calls for prospective cohort studies to investigate the association of WBV and low back pain [16].

Experiences with WBV-related musculoskeletal symptoms may not be limited solely to the back. LBD include a broad spectrum of conditions with a variety of etiologies, such as: low back pain and low back injuries [19]. Frank et al. described low back pain as “any back pain between the ribs and top of the leg from any cause”[20]. Anatomically, due the closeness of the hip and lumbopelvic region, hip symptoms and function may be related to LBDs [21]. “Lower back and hip pains are often experienced together, making it a common combination of symptoms (syndrome)” [22]. Also, problems originating at the low back may refer pain to the hip [23], and leg [24]. In addition to referred pain to the hip, local hip pathology may either mimic or co-exist with LBDs. Thelin’s work on the health of farmers found a connection between prolonged tractor driving and increased risks for back trouble as well as radiologically confirmed hip-joint arthritis [25].

Farming is a heterogeneous occupation with many kinds of commodities and production methods, so exposures can also be varied. Worker traits, behaviours, work settings and organizational structures account for the distinctiveness in farming among occupations [26, 27]. WBV likely works over a long period to produce mechanical effect [7, 28], but it is not clear how long it takes to begin observing symptoms. LBDs are affected by factors in many dimensions, not only physical exposures or risk factors. According to Pincus et al. “the biopsychosocial model of back pain has become a dominant model in the conceptualization of the etiology and prognosis of back pain” [29].

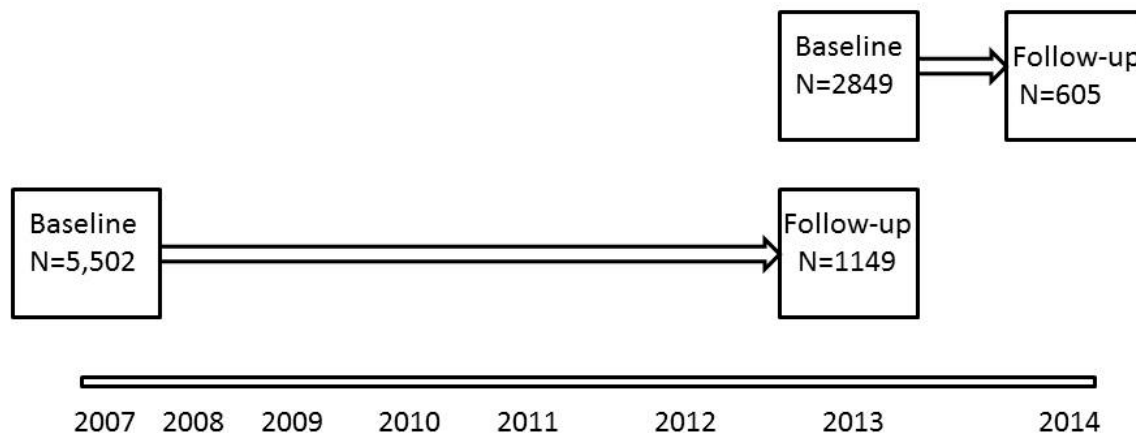
Although there seems to be an association between LBDs and WBV; the causal relationship is not clear. The purpose of this study was to determine the strength and statistical significance of associations between WBV and LBDs among farmers through the use of a prospective cohort design. Associations between hip and lower limb symptoms and WBV were investigated and important biopsychosocial covariates were considered. All associations were investigated based on 6-year follow-up (cohort 1) and 1-year follow-up (cohort 2), to explore the potential effects of exposure accumulation.

### 4.3 Methodology

The data source was the Saskatchewan Farm Injury Cohort Study. Recruitment strategies and the study questionnaires were pilot tested and refined on multiple occasions [30]. In 2007, baseline data were collected via postal questionnaire from 5,492 individuals on 2,390 farms in 50 rural municipalities within Saskatchewan [30]. Follow-up data on musculoskeletal symptoms were collected in 2013 (six-year follow-up) from 1149 farmer participants on 582 of the farms originally involved in the 2007 baseline study. In addition to these returning farmers, in 2013 1,699 new farmers on 658 new farms filled in baseline questionnaires for the first time. Participants from the 2013 baseline were followed-up in 2014 (1-year follow-up). This resulted in two datasets for each of two cohorts: 1) the first cohort with 1,149 farm people who had been followed for six years, and 2) the second with 605 participants who had been followed for one year.

For the cohort 1, musculoskeletal (MSK) outcomes were not assessed at baseline, so it was not possible to determine whether MSK symptoms exist. Hence, the cohort 1 operates on the

assumption that MSK symptoms at baseline were negligible, and that every case at follow up is an 'incident' case. Alternatively, the cohort 1 can be considered a cross-sectional design with asynchronous recording of exposure and health outcome. For the cohort 2, MSK symptoms were available at baseline and those with low back symptoms at baseline were eliminated, making cohort 2 a true prospective cohort.



**Figure 6: Baseline and follow-up sample sizes for the six-year and one-year cohorts**

#### **4.3.1 Questionnaire: Whole body vibration exposure**

Information on exposure to vibrating equipment or vehicles was measured in terms of hours per year of operating tractors, and combines, and days per year operating all-terrain vehicles. Hours were categorized into four groups (zero exposure, plus tertiles of the remainder) per exposure type in cohort 1: 0, 1-150, 151-400 and 401+ for tractor operation, 0, 1-60, 61-150 and 151+ for combines operation, and ATV categories of, 0, 1-20, 21-80 and 81+ days per year. In cohort 2, hour of exposure to farm machinery were divided into three groups: 0, 1-250 and

251+ for tractor operation, 0, 1-120, and 121+ for combine operation and 0, 1-60, 61+ days/year for ATV operation. Questions on farm machinery use were pilot tested on a convenience sample of farmers to test for face validity and ease of interpretation. Questions to assess demographic and farm characteristics used standard categories and were also pilot tested and refined. [30].

#### **4.3.2 Questionnaire: personal and farm characteristics as potential confounder**

A biopsychosocial model of LBDs was considered for this study, acknowledging that back disorders develop and progress within a context that includes physical, psychological, biological, and social factors [31, 32]. A range of potential confounders were available from the 2013 and 2014 follow-up study instruments. Farm characteristics such as operating arrangements on farms were considered: “individual family farm”, “partnership”, “family corporation”, and “other types”. The primary commodities produced on farm were categorised as: “grain crops”, “cattle (beef)”, “cattle (dairy)”, “pigs”, “poultry”, “vegetables or fruit”, and “other animals”.

Potential confounding variables found in the in 2013 database were age, gender, and education. Age was divided into five categories for cohort : “less than or equal to 19 years”, “20-39 years”, “40-55 years”, “56-75 years”, and “76 years and above” and three categories for cohort 2: “less than or equal to 50 years”, “51-60 years” and 61 years and above”. Education level attained by farmer participants was also categorized into four levels: “less than high school”, “completed high school”, “completed University”, and “institutions other than above”. Besides the potential confounding variables captured in the 2013 database, the 2014 also captured additional potential confounding variables which include: BMI, smoking, depression,

height, weight, and other farm tasks (shoveling, heavy lifting, and hands above shoulders). Depression and smoking were reported as “yes/no”. BMI was divided into three categories: “normal”, “overweight”, and “obese”. Weight was also included as four categories: “less than or equal to 120 pounds”, “121-160 pounds”, “161-190 pounds”, and “191 pounds and above”. Similarly, height was also categories into four: “less than or equal to 60 inches”, “ 61-65 inches”, “66-70 inches”, and “71 inches and above”. Physically demanding farm tasks were also assessed by the questionnaire: heavy lifting, shoveling, and working with hands above shoulder. Heavy lifting was categorized as “none”, “1-10 days per year”, “11-20 days per year”, and “50 days per year and above”. Likewise, shoveling was also included as four categories: “none”, “1-10 days per year”, “11-20 days per year”, and “20 days per year and above”. Hands above shoulder were assessed based on days exposed to working with hands above shoulder in days per year. The categories were “none”, “1-5 days per year”, “6-16 days per year”, and “16 days per year and above”.

#### **4.3.3 Questionnaire: musculoskeletal symptoms as an outcome**

Questions on musculoskeletal symptoms were selected from the Standardised Nordic Questionnaire (SNQ) for the analysis of musculoskeletal symptoms [33]. Farmer participants were asked to answer “yes” or “no” to two questions that requested information on 9 body parts (neck, shoulder, elbows, wrist/hands, upper back, low back, hips/thighs, knees, and ankles/feet): question 1) trouble (aches, pain, discomfort) experienced in the last 12 months; and question 2) whether the symptoms prevented them from doing their normal work (at home or away from home) in the last 12 months. Here question one is referred to as “Any musculoskeletal symptoms” and question two as “Interrupting musculoskeletal symptoms”.

The SNQ has been tested in terms of validity by comparing clinical diagnosis [33], and in terms of its reliability [33]. The test-retest method used to assess the reliability of the SNQ comprising samples 19-29 workers of three separate studies ranged from 0 to 23% disagreement while its validity was tested by comparing clinical history of two separate studies with samples 19 and 20 workers varied between 0-20% disagreement [33, 34]. In addition, the reliability and validity of the SNQ is considered acceptable for use in workplace ergonomics [34]. Previous study on the sensitivity and specificity evaluation of the SNQ using clinical examination as the reference method, found the sensitivity in a range of situations ranging from 82.3% to 100% and specificity from 51.1% to 82.4% [35].

#### 4.3.4 Data analysis

A modified Poisson regression was performed using both SAS 9.4 and SPSS version 22. Modified (also called robust) Poisson models are increasingly being used in situations where outcomes are highly prevalent [36-38]. Clustering was incorporated into the models through the use of generalised estimating equations (GEEs). This GEE assumed an exchangeable working correlation, based on published recommendations [39-41]. To avoid the pitfall of colinearity between independent variables, Spearman's correlation coefficients were used to assess correlation. When variables were highly correlated ( $\rho > 0.7$ ) [42], the variable with stronger biological plausibility or literature supporting a relationship with the health outcome was kept in the models.

Our modeling strategy considered biological plausibility as informed by the literature, and statistical evidence generated from initial bivariate analyses, backwards elimination, and

change in estimate approaches. Based on the model techniques described by Hosmer et al., all variables with a p-value < 0.25 in the bivariate analysis qualified for inclusion into the multivariate analysis [43]. In the case of categorical variable of three or more categories, the overall p-value was used to determine their inclusion. Backward elimination procedures were used to select a parsimonious list of the most contributing predictors ( $p < 0.05$ ) for the final model. Possible interactions terms between WBV exposure (tractor, combine, and ATV) and psychosocial factor including depression and smoking were tested as recommended by Devereux et al. [44]. A variable was deemed a possible confounder if there was at least 20% change in estimate approach [45].

#### 4.4 Results

Table 5 summarizes the population and work characteristics of cohorts 1 and 2, demonstrating that the majority of farmer participants were males for both the cohort 1 and cohort 2, (60.6%) and (59.1%) respectively. However, in cohort 1 most of the farmer participants were between the ages of 40 and 55 years (46.3%) while in cohort 2 were more often between the ages of 56 and 75 years (41.2%). In addition, both cohorts showed majority of farmers surveyed had completed high school. In cohort 1, tractor operation was reported by 838 (72.9%), combine by 584 (50.8%), and ATV by 504 (43.9%). A similar pattern of exposure to tractor operation was observed in the cohort 2 with 1957 (68.6%) of participants reporting exposure to tractor operation, while a pattern of increased exposure to ATV was seen with 1550 (54.4%) reporting. The additional variables available in cohort 2 revealed that 118 (4.1%) of farmer participants had been diagnosed of depression while 216 (7.6%) smoke. Furthermore, most farmers (321,

53.1%) were within the height range of 66-70 inches, and 883 (31.0%) had weight 191lbs and above. The body mass index categorization found that 1036 (36.4%) of farmer participants were overweight. Other work characteristics revealed that, most farmer participants performed heavy lifting and shoveling more between 1-10 days per year.

Tables 6 summarizes cohort 2 demographic and farm characteristics of farmers with and without LBD at baseline and follow-up. In the cohort 2 baseline data, the majority of farmer participants (1512, 54.0%) reported a history of “Any back symptoms. However, the pattern was different in the case of Interrupting back symptoms, as majority of farmers were free of “Interrupting back symptoms” 2394 (85.7%).

The present study also assessed the relationship between WBV and hip symptoms; table 7 presents the demographic and farm characteristics of farmer participants with and without “Any hip symptoms” and “Interrupting hip symptoms”. In all, the majority of farmer participants did not report hip symptoms, with only 799 (28.5%) and 163 (5.8%) reported having “Any hip symptoms” and “Interrupting hip symptoms”, respectively, at baseline.

Although a large number of participants were free of both “Any hip symptoms” and “Interrupting hip symptoms” at baseline, only 388 (any hip symptoms) and 562 (interrupting hip symptoms) responded in the follow-up.

Tables 8 summarizes the findings of both bivariate and multivariate analysis of the associations of WBV with LBDs in cohort 1. The adjusted models in table 8 showed significant associations between WBV and LBD in some exposure categories. For combine and ATV use, no significant relationship was found after accounting for potential confounders for either “Any back



symptoms” or “Interrupting back symptoms”. Also, a dose-response relationship was found for accumulated WBV exposure among tractor operators exposed to 1-150hrs/year (RR=1.23, 95%CI: 1.05-1.44), 151-400hrs/year (RR= 1.32, 95%CI: 1.14-1.54) and 401+hrs/year (RR=1.34, 95%CI: 1.15-1.56) and “Any back symptoms”. Overall, more associations were found with “Any back symptoms” than “Interrupting back symptoms”.

Table 9 shows the findings of bivariate analysis of the association between WBV and LBDs in cohort 2. In contrast to the cohort 1 results in table 8, table 9 does not show any of the farm machinery investigated in cohort 2 to be significantly associated in bivariate analysis for either “Any back symptoms” or “Interrupting back symptoms”. Hence, further multivariate analyses were not pursued.

Table 10 shows results of bivariate and adjusted models for cohort 1. Findings of the adjusted model also showed no significant relationship in all three farm vehicles (tractor, combine and ATV) and “Interrupting hip symptoms” after accounting for potential confounding variables. The strongest adjusted association was found in tractor operation for 151-400 hours per year (RR = 1.95, 95% CI 1.45-2.62), 401 +hours per year (RR = 1.79, 95% CI 1.32-2.45) and “Any hip symptoms” in cohort 1. As with “Any back symptoms” and “Interrupting back symptoms” in cohort 2, no significant bivariate association was found for any of the three farm vehicles and either “Any hip symptoms” or “Interrupting hip symptoms” (see table 11).

**Table 5 Personal, Farm, and Work Characteristics of Participating Farm People**

<b>Variables</b>	<b>Cohort 1 Follow up N= 1149</b>		<b>Cohort 2 Baseline N=2849</b>	
<b>Age</b>				
<= 19	87	(7.6%)	267	(9.4%)
20-39	142	(12.4%)	423	(14.8%)
40-55	532	(46.3%)	802	(28.2%)
56-75	347	(30.2%)	1174	(41.2)
76+	27	(2.3%)	174	(6.1%)
Missing	14	(1.2%)	9	(0.3%)
<b>Sex</b>				
Female	453	(39.4%)	1153	(40.5%)
Male	696	(60.6%)	1685	(59.1%)
Missing			11	(0.4%)
<b>Education</b>				
Less than high school	252	(21.9%)	593	(20.8%)
Completed high school	397	(34.6%)	971	(34.1%)
Completed university	255	(22.2%)	558	(19.6%)
Institution other than above	240	(20.9%)	711	(25.0%)
Missing	5	(0.4%)	16	(0.6%)
<b>Tractor operation hrs/year</b>				
None	256	(22.3%)	714	(25.1%)
1-150	338	(29.4%)	647	(22.7%)
151-400	253	(22.0%)	756	(26.5%)
401+	247	(21.5%)	554	(19.4%)
Missing	55	(4.8%)	178	(6.2%)
<b>Combines operation hrs/yr</b>				
None	476	(41.4%)	1230	(43.2%)
1-60	196	(17.1%)	463	(16.3%)
61-150	214	(18.6%)	494	(17.3%)
151+	174	(15.1%)	444	(15.6%)
Missing	89	(7.8%)	218	(7.7%)
<b>ATV operation hrs/year</b>				
None	559	(48.7%)	1134	(39.8%)
1-20	233	(20.3%)	513	(18.0%)
21-80	144	(12.5%)	571	(20.0%)
81+	127	(11.1%)	466	(16.4%)
Missing	86	(7.4%)	165	(5.8%)
<b>Depression</b>				
No			2731	(95.9%)
Yes			118	(4.1%)
Missing				

**Table 5 (Continued)**

<b>Smoking</b>			
No		2608	(91.5%)
Yes		216	(7.6%)
Missing		25	(0.9%)
<b>Height (Inches)</b>			
<=60		199	(7.0%)
61-65		643	(22.6%)
66-70		1176	(41.3%)
71+		750	(26.3%)
Missing		81	(2.8%)
<b>BMI</b>			
Normal		914	(32.1%)
Overweight		1036	(36.4%)
Obese		669	(23.5%)
Missing		230	(8.1%)
<b>Weight (Pounds)</b>			
< = 120		246	(8.6%)
121-160		765	(26.9%)
161-190		782	(27.4%)
191+		883	(31.0%)
Missing		173	(6.1%)
<b>Heavy lifting days/year</b>			
None		1299	(45.6%)
1-10		528	(18.5%)
11-50		421	(14.8%)
>50		396	(13.9%)
Missing		205	(7.2%)
<b>Shovelling days/year</b>			
None		1250	(43.9%)
1-10		733	(25.7%)
11-20		238	(8.4%)
>20		443	(15.5%)
Missing		185	(6.5%)
<b>Hands above days/year</b>			
None		1493	(52.4%)
1-5		416	(14.6%)
6-16		337	(11.8%)
>16		370	(13.0%)
Missing		233	(8.2%)
<b>LBD Symptoms</b>			
Any symptoms		59.8%	
Interrupting		17.9%	

**Table 6: Demographic and Farm Characteristics of Farmers with and without LBD at Baseline and Follow-up for Cohort 2**

Variables	Baseline				Follow-up			
	Without Any Symptoms (N=1289)	LBD Interrupting (N=2394)	With Any Symptoms (N=1512)	LBD Interrupting (N=398)	Without Any Symptoms (N=200)	LBD Interrupting (N=499)	With Any Symptoms (N=405)	LBD Interrupting (N=104)
<b>Age</b>								
<=50	613 (47.6%)	945 (39.5%)	455 (30.1%)	118 (29.6%)	41 (20.5%)	102 (20.4%)	77 (19.0%)	18 (17.3%)
51-60	303 (23.5%)	699 (29.2%)	540 (35.7%)	141 (35.4%)	67 (33.5%)	184 (36.9%)	164 (40.5%)	45 (43.3%)
61+	370 (28.7%)	745 (31.1%)	515 (34.1%)	138 (34.7%)	92 (46.0%)	213 (42.7%)	163 (40.2%)	41 (39.4%)
Missing	3 (0.2%)	5 (0.2%)	2 (0.1%)	1 (0.3%)			1 (0.3%)	
<b>Sex</b>								
Female	568 (44.1%)	981 (41.0%)	563 (37.2%)	145 (36.4%)	58 (29.0%)	134 (26.9%)	97 (23.9%)	22 (21.2%)
Male	718 (55.7%)	1405 (58.7%)	944 (62.4%)	252 (63.3%)	141 (70.5%)	364 (72.9%)	306 (75.6%)	81 (77.9%)
Missing	3 (0.2%)	8 (0.3%)	5 (0.3%)	1 (0.3%)	1 (0.5%)	1 (0.2%)	2 (0.5%)	1 (0.9%)
<b>Education</b>								
Less than high school	326 (25.3%)	516 (21.6%)	254 (16.8%)	63 (15.8%)	28 (14.0%)	71 (14.2%)	56 (13.8%)	14 (13.5%)
Completed high School	414 (32.1%)	798 (33.3%)	542 (35.8%)	153 (38.5%)	78 (39.0%)	180 (36.1%)	140 (34.6%)	35 (33.7%)
Completed University	240 (18.6%)	467 (19.5%)	308 (20.4%)	80 (20.1%)	44 (22.0%)	122 (24.4%)	105 (25.9%)	29 (27.9%)
Inst. Other than above	304 (23.6%)	603 (25.2%)	402 (26.6%)	100 (25.1%)	49 (24.5%)	125 (25.1%)	102 (25.2%)	25 (24.0%)
Missing	5 (0.4%)	10 (0.4%)	6 (0.4%)	2 (0.5%)	1 (0.5%)	1 (0.2%)	2 (0.5%)	1 (0.9%)
<b>Tractor Operation hrs/yr</b>								
None	416 (32.3%)	620 (25.9%)	283 (18.7%)	75 (18.8%)	31 (15.5%)	69 (13.8%)	49 (12.1%)	12 (11.5%)
1-250	554 (43.0%)	1024 (42.8%)	651 (43.1%)	179 (45.0%)	95 (47.5%)	223 (44.7%)	175 (43.2%)	46 (44.2%)
251	255 (19.8%)	603 (25.2%)	479 (31.7%)	128 (32.2%)	64 (32.0%)	179 (35.9%)	158 (39.0%)	42 (40.4%)
Missing	64 (4.9%)	147 (6.1%)	99 (6.5%)	16 (4.0%)	10 (5.0%)	28 (5.6%)	23 (5.7%)	4 (3.9%)
<b>Combine Operation hrs/yr</b>								
None	630 (48.9%)	1056 (44.1%)	579 (38.3%)	152 (38.2%)	62 (31.0%)	151 (30.3%)	119 (29.4%)	30 (28.8%)
1-120	356 (27.6%)	687 (28.7%)	464 (30.7%)	132 (33.2%)	71 (35.5%)	178 (35.7%)	150 (37.0%)	42 (40.4%)
121+	218 (16.9%)	480 (20.1%)	353 (23.3%)	90 (22.6%)	51 (25.5%)	133 (26.6%)	108 (26.7%)	26 (25.0%)
Missing	85 (6.6%)	171 (7.1%)	116 (7.6%)	24 (6.0%)	16 (8.0%)	37 (7.4%)	28 (6.9%)	6 (5.8%)
<b>ATV Operation hrs/yr</b>								
None	569 (44.0%)	967 (40.4%)	548 (36.2%)	146 (36.7%)	78 (39.0%)	175 (35.1%)	135 (33.3%)	37 (35.6%)
1-60	490 (38.0%)	920 (38.4%)	584 (38.6%)	151 (37.9%)	80 (40.0%)	209 (41.9%)	169 (41.7%)	41 (39.4%)
61+	163 (13.0%)	376 (15.7%)	298 (19.7%)	83 (20.9%)	29 (14.5%)	89 (17.8%)	86 (21.0%)	24 (23.1%)
Missing	67 (5.0%)	131 (5.5%)	82 (5.4%)	18 (5.0%)	13 (6.5%)	26 (5.2%)	15 (4.0%)	2 (1.9%)

Table 6 (Continued)

<b>Depression</b>								
Yes	35 (2.7%)	84 (3.5%)	83 (5.5%)	34 (8.5%)	2 (1.0%)	10 (2.0%)	21 (5.2%)	13 (12.5%)
No	1254 (97.3%)	2309 (96.5%)	1429 (94.5%)	364 (91.5%)	198 (99.0%)	489 (98.0%)	383 (94.5%)	91 (87.5%)
Missing							1 (0.3%)	
<b>Smoking</b>								
Yes	92 (7.1%)	173 (7.3%)	119 (7.9%)	38 (9.5%)	10 (5.0%)	32 (6.4%)	27 (6.7%)	7 (6.7%)
No	1188 (92.2%)	2206 (92.7%)	1388 (91.8%)	360 (90.5%)	189 (94.5%)	465 (93.2%)	376 (92.8%)	97 (93.3%)
Missing	9 (0.7%)		5 (0.3%)		1 (0.5%)	2 (0.4%)	2 (0.5%)	
<b>Height (Inches)</b>								
<=60	122 (9.5%)	165 (6.9%)	67 (4.4%)	24 (6.0%)	1 (0.5%)	8 (1.6%)	13 (3.2%)	5 (4.8%)
61-65	320 (24.8%)	567 (23.7%)	318 (21.0%)	70 (17.6%)	35 (17.5%)	87 (17.4%)	60 (15.0%)	8 (7.7%)
66-70	483 (37.5%)	973 (40.6%)	675 (44.6%)	182 (45.7%)	108 (54.0%)	261 (52.3%)	212 (52.3%)	59 (56.7%)
71+	326 (25.3%)	623 (26.0%)	415 (27.5%)	113 (28.4%)	53 (26.5%)	139 (27.9%)	116 (28.6%)	31 (29.8%)
Missing	38 (2.9%)	60 (2.8%)	37 (2.5%)	9 (2.3%)	3 (1.5%)	4 (0.8%)	4 (0.9%)	1 (1%)
<b>BMI</b>								
Normal	478 (37.1%)	782 (32.7%)	417 (27.6%)	110 (27.7%)	57 (28.5%)	129 (25.9%)	94 (23.2%)	22 (21.2%)
Overweight	437 (33.9%)	871 (36.4%)	591 (39.1%)	155 (38.9%)	89 (44.5%)	225 (45.0%)	183 (45.2%)	47 (45.2%)
Obese	257 (19.9%)	555 (23.2%)	407 (26.9%)	106 (26.6%)	47 (23.5%)	133 (26.7%)	115 (28.4%)	28 (26.9%)
Missing	117 (9.1%)	186 (7.7%)	97 (6.4%)	27 (6.8%)	7 (3.5%)	12 (2.4%)	13 (3.2%)	7 (6.7%)
<b>Weight (pounds)</b>								
<=120	179 (13.9%)	224 (9.4%)	61 (4.0%)	16 (4.0%)	6 (3.0%)	10 (2.0%)	5 (1.2%)	1 (1%)
121-160	393 (30.5%)	654 (27.3%)	356 (23.5%)	93 (23.4%)	52 (26.0%)	117 (23.4%)	84 (20.7%)	18 (17.3%)
161-190	309 (24.0%)	650 (27.2%)	465 (30.8%)	121 (30.4%)	59 (29.5%)	160 (32.1%)	137 (34.0%)	37 (35.6%)
191+	333 (25.8%)	727 (30.3%)	540 (35.7%)	143 (35.9%)	78 (39.0%)	203 (40.7%)	168 (41.4%)	42 (40.4%)
Missing	75 (5.8%)	139 (5.8%)	90 (6.0%)	25 (6.3%)	5 (2.5%)	9 (1.8%)	11 (2.7%)	6 (5.7%)
<b>Heavy Lifting days/yr</b>								
None	706 (54.8%)	1134 (47.4%)	576 (38.1%)	140 (35.2%)	79 (39.5%)	179 (35.9%)	128 (31.6%)	26 (25.0%)
1-10	217 (16.8%)	429 (17.9%)	304 (20.1%)	91 (22.9%)	51 (25.5%)	126 (25.3%)	108 (26.7%)	32 (30.8%)
11-50	150 (11.6%)	344 (14.4%)	268 (17.7%)	74 (18.6%)	30 (15.0%)	87 (17.4%)	77 (19.0%)	21 (20.2%)
<50	135 (10.5%)	320 (13.4%)	258 (17.1%)	73 (18.3%)	26 (13.0%)	80 (16.0%)	76 (18.7%)	21 (20.2%)
Missing	81 (6.3%)	167 (6.9%)	106 (7.0%)	20 (5.0%)	14 (7.0%)	27 (5.4%)	16 (4.0%)	4 (3.8%)

Table 6 (Continued)

<b>Shovelling days/yr</b>								
None	677 (52.5%)	1087 (45.4%)	557 (36.8%)	139 (34.9%)	84 (42.0%)	174 (34.9%)	123 (30.4%)	30 (28.8%)
1-10	302 (23.4%)	603 (25.2%)	423 (28.0%)	121 (30.4%)	61 (30.5%)	174 (34.9%)	147 (36.3%)	35 (33.7%)
11-20	76 (5.9%)	190 (7.9%)	160 (10.6%)	46 (11.6%)	16 (8.0%)	45 (9.0%)	41 (10.1%)	13 (12.5%)
>20	158 (12.3%)	364 (15.2%)	280 (18.5%)	74 (18.6%)	29 (14.5%)	83 (16.6%)	75 (18.5%)	21 (20.2%)
Missing	76 (5.9%)	150 (6.3%)	92 (6.1%)	18 (4.5%)	10 (5.0%)	23 (4.6%)	19 (4.7%)	5 (4.8%)
<b>Hands above days/yr</b>								
None	789 (61.2%)	1288 (53.8%)	688 (45.5%)	180 (45.2%)	97 (48.5%)	221 (44.3%)	168 (41.5%)	43 (41.3%)
1-5	169 (13.1%)	346 (14.4%)	241 (15.9%)	64 (16.1%)	44 (22.0%)	105 (21.0%)	75 (18.5%)	14 (13.5%)
6-16	118 (9.2%)	272 (11.4%)	214 (14.2%)	60 (15.1%)	29 (14.5%)	70 (14.1%)	62 (15.3%)	20 (19.2%)
>16	124 (9.6%)	301 (12.6%)	245 (16.2%)	68 (17.1%)	17 (8.5%)	68 (13.6%)	72 (17.8%)	22 (21.2%)
Missing	86 (6.9%)	187 (7.8%)	124 (8.2%)	26 (6.5%)	13 (6.5%)	35 (7.0%)	28 (6.9%)	5 (4.8%)

**Table 7: Demographic and Farm Characteristics of Farmers with and without Hip Symptoms at Baseline and Follow-up for Cohort 2**

Variables	Baseline				Follow-up			
	Without LBD		With LBD		Without LBD		With LBD	
	Any Symptoms (N=2001)	Interrupting (N=2631)	Any Symptoms (N=799)	Interrupting (N=163)	Any Symptoms (N=388)	Interrupting (N=562)	Any Symptoms (N=214)	Interrupting (N=42)
<b>Age</b>								
<=50	893 (44.6%)	1031 (39.2%)	177 (22.2%)	35 (21.5%)	91 (23.4%)	112 (19.9%)	28 (13.1%)	8 (19.0%)
51-60	540 (27.0%)	778 (29.6%)	303 (37.9%)	62 (38.0%)	133 (34.3%)	211 (37.5%)	98 (45.8%)	18 (42.9%)
61+	564 (28.2%)	817 (31.1%)	318 (39.8%)	66 (40.5%)	164 (42.3%)	239 (42.5%)	88 (41.1%)	16 (38.1%)
Missing	4 (0.2%)	5 (0.1%)	1 (0.1%)					
<b>Sex</b>								
Female	761 (38.0%)	1051 (39.9%)	370 (46.3%)	76 (46.6%)	82 (21.1%)	139 (24.7%)	72 (33.6%)	17 (40.5%)
Male	1234 (61.7%)	1572 (59.8%)	427 (53.4%)	87 (53.4%)	305 (78.6%)	421 (75.0%)	141 (65.9%)	25 (59.5%)
Missing	6 (0.3%)	8 (0.3%)	2 (0.3%)		1 (0.3%)	2 (0.3%)	1 (0.5%)	
<b>Education</b>								
Less than high school	438 (21.9%)	543 (20.6%)	142 (17.7%)	37 (22.7%)	51 (13.1%)	76 (13.5%)	34 (15.9%)	9 (21.4%)
Completed high School	665 (33.2%)	894 (34.0%)	290 (36.3%)	58 (35.6%)	148 (38.1%)	205 (36.4%)	69 (32.2%)	11 (26.2%)
Completed University	398 (19.9%)	523 (19.9%)	150 (18.8%)	25 (15.3%)	96 (24.8%)	142 (25.3%)	52 (24.3%)	9 (21.4%)
Inst. Other than above	492 (24.6%)	661 (25.1%)	214 (26.8%)	42 (25.8%)	92 (23.7%)	138 (24.6%)	58 (27.1%)	12 (28.6%)
Missing	8 (0.4%)	10 (0.4%)	3 (0.4%)	1 (0.6%)	1 (0.3%)	1 (0.2%)	1 (0.5%)	1 (2.4%)
<b>Tractor Operation hrs/yr</b>								
None	519 (25.9%)	660 (25.1%)	180 (22.5%)	36 (22.1%)	47 (12.1%)	73 (13.0%)	32 (14.9%)	8 (19.0%)
1-250	867 (43.3%)	1127 (42.8%)	339 (42.4%)	78 (47.9%)	171 (44.1%)	247 (44.0%)	99 (46.3%)	23 (54.8%)
251	497 (24.8%)	689 (26.2%)	235 (29.4%)	42 (25.8%)	147 (37.9%)	213 (37.9%)	74 (34.6%)	8 (19.0%)
Missing	118 (6.0%)	155 (5.9%)	45 (5.6%)	7 (4.2%)	23 (5.9%)	29 (5.1%)	9 (4.2%)	3 (7.1%)
<b>Combine Operation hrs/yr</b>								
None	837 (41.8%)	1123 (42.9%)	371 (46.4%)	81 (49.7%)	94 (24.2%)	161 (28.6%)	86 (40.2%)	20 (47.6%)
1-120	615 (30.7%)	775 (29.5%)	204 (25.5%)	44 (27.0%)	156 (40.2%)	206 (36.7%)	65 (30.4%)	15 (35.7%)
121+	406 (20.3%)	543 (20.6%)	166 (20.8%)	28 (17.2%)	106 (27.3%)	154 (27.4%)	52 (24.3%)	5 (11.9%)
Missing	143 (7.2%)	190 (7.0%)	58 (7.3%)	10 (6.1%)	32 (8.3%)	41 (7.3%)	11 (5.1%)	2 (4.8%)
<b>ATV Operation hrs/yr</b>								
None	802 (40.1%)	1053 (40.0%)	312 (39.0%)	61 (37.4%)	138 (35.6%)	198 (35.2%)	74 (34.6%)	15 (35.7%)
1-60	768 (38.4%)	1007 (38.3%)	307 (38.4%)	65 (39.9%)	159 (41.0%)	231 (41.1%)	89 (41.6%)	19 (45.2%)
61+	320 (16.0%)	430 (16.3%)	142 (17.8%)	30 (18.4%)	67 (17.3%)	105 (18.7%)	47 (21.9%)	8 (19.0%)
Missing	111 (5.5%)	114 (5.4%)	38 (4.8%)	7 (4.3%)	24 (6.1%)	28 (5.0%)	4 (1.9%)	

Table 7 (Continued)

<b>Depression</b>								
Yes	70 (3.5%)	105 (4.0%)	47 (5.9%)	13 (8.0%)	11 (2.8%)	21 (3.7%)	12 (5.6%)	2 (4.8%)
No	1931 (96.5%)	2526 (96.0%)	752 (94.1%)	150 (92.0%)	377 (97.2%)	541 (96.3%)	202 (94.4%)	40 (95.2%)
Missing								
<b>Smoking</b>								
Yes	158 (7.9%)	194 (7.4%)	53 (6.6%)	17 (10.4%)	28 (7.2%)	37 (6.6%)	8 (3.7%)	5 (11.9%)
No	1832 (91.6%)	2423 (92.1%)	742 (92.9%)	145 (89.0%)	359 (92.5%)	523 (93.1%)	205 (95.8%)	37 (88.1%)
Missing	11 (0.5%)	14 (0.5%)	4 (0.5%)	1 (0.6%)	1 (0.3%)	2 (0.3%)	1 (0.5%)	
<b>Height (Inches)</b>								
<=60	147 (7.4%)	178 (6.8%)	42 (5.3%)	11 (6.7%)	6 (1.5%)	10 (1.8%)	7 (3.3%)	3 (7.1%)
61-65	417 (20.8%)	601 (22.8%)	221 (27.7%)	36 (22.1%)	47 (12.1%)	89 (15.8%)	49 (22.9%)	7 (16.7%)
66-70	812 (40.6%)	1079 (41.0%)	346 (43.3%)	77 (47.2%)	211 (54.4%)	296 (52.7%)	108 (50.5%)	24 (57.1%)
71+	568 (28.4%)	703 (26.7%)	172 (21.5%)	35 (21.5%)	119 (30.7%)	162 (28.8%)	49 (22.8%)	7 (16.7%)
Missing	57 (2.8%)	70 (2.7%)	18 (2.2%)	4 (2.5%)	5 (1.3%)	5 (0.9%)	1 (0.5%)	1 (2.4%)
<b>BMI</b>								
Normal	684 (34.2%)	854 (32.5%)	211 (26.4%)	39 (23.9%)	102 (26.3%)	143 (25.4%)	49 (22.9%)	8 (19.0%)
Overweight	728 (36.4%)	958 (36.4%)	299 (37.4%)	69 (42.3%)	183 (47.2%)	249 (44.3%)	88 (41.1%)	23 (54.8%)
Obese	423 (21.1%)	615 (23.4%)	241 (30.2%)	47 (28.9%)	91 (23.5%)	152 (27.1%)	70 (32.7%)	10 (23.8%)
Missing	166 (8.3%)	204 (7.7%)	48 (6.0%)	8 (4.9%)	12 (3.0%)	18 (3.2%)	7 (3.3%)	1 (2.4%)
<b>Weight (pounds)</b>								
<=120	205 (10.2%)	236 (9.0%)	35 (4.4%)	4 (2.5%)	7 (1.8%)	10 (1.8%)	4 (1.9%)	1 (2.4%)
121-160	538 (26.9%)	699 (26.6%)	211 (26.4%)	48 (29.4%)	85 (21.9%)	124 (22.1%)	51 (23.8%)	11 (26.2%)
161-190	525 (26.3%)	721 (27.4%)	248 (31.0%)	51 (31.3%)	125 (32.2%)	178 (31.7%)	69 (32.2%)	19 (45.2%)
191+	613 (30.6%)	820 (31.2%)	260 (32.5%)	52 (31.9%)	162 (41.8%)	236 (42.0%)	84 (39.3%)	10 (23.8%)
Missing	120 (6.0%)	155 (5.8%)	45 (5.6%)	8 (4.9%)	9 (2.3%)	14 (2.4%)	6 (2.8%)	1 (2.4%)
<b>Heavy Lifting days/yr</b>								
None	940 (47.0%)	1205 (45.8%)	339 (42.4%)	71 (43.6%)	121 (31.2%)	186 (33.1%)	86 (40.2%)	20 (47.6%)
1-10	381 (19.0%)	492 (18.7%)	141 (17.6%)	28 (17.2%)	113 (29.1%)	153 (27.2%)	43 (20.1%)	5 (11.9%)
11-50	292 (14.6%)	386 (14.7%)	126 (15.8%)	32 (19.6%)	65 (16.8%)	99 (17.6%)	42 (19.6%)	9 (21.4%)
<50	260 (13.0%)	370 (14.1%)	134 (16.8%)	24 (14.7%)	67 (17.3%)	94 (16.7%)	34 (15.9%)	7 (16.7%)
Missing	128 (6.4%)	178 (6.7%)	59 (7.4%)	8 (4.9%)	22 (5.6%)	30 (5.4%)	9 (4.2%)	1 (2.4%)



Table 7 (continued)

<b>Shovelling days/yr</b>								
None	895 (44.7%)	1157 (44.0%)	336 (42.1%)	71 (43.6%)	132 (34.0%)	190 (33.8%)	74 (34.6%)	15 (35.7%)
1-10	528 (26.4%)	681 (25.9%)	198 (24.8%)	43 (26.4%)	138 (35.6%)	196 (34.9%)	69 (32.2%)	13 (31.0%)
11-20	168 (8.4%)	224 (8.5%)	68 (8.5%)	12 (7.4%)	38 (9.8%)	55 (9.8%)	20 (9.3%)	3 (7.1%)
>20	299 (14.9%)	409 (15.5%)	140 (17.5%)	30 (18.4%)	63 (16.2%)	94 (16.7%)	41 (19.2%)	10 (23.8%)
Missing	111 (5.6%)	160 (6.1%)	57 (7.1%)	7 (4.2%)	17 (4.4%)	27 (4.8%)	10 (4.7%)	1 (2.4%)
<b>Hands above days/yr</b>								
None	1084 (54.2%)	1390 (52.8%)	390 (48.8%)	80 (49.1%)	167 (43.0%)	244 (43.4%)	97 (45.3%)	21 (50.0%)
1-5	279 (13.9%)	384 (14.6%)	131 (16.4%)	26 (16.0%)	84 (21.7%)	113 (20.1%)	34 (15.9%)	6 (14.3%)
6-16	239 (11.9%)	310 (11.8%)	95 (11.9%)	23 (14.1%)	58 (14.9%)	83 (14.8%)	32 (14.9%)	7 (16.7%)
>16	262 (13.1%)	346 (13.2%)	107 (13.4%)	23 (14.1%)	56 (14.4%)	83 (14.8%)	34 (15.9%)	3 (7.1%)
Missing	137 (6.9%)	201 (7.6%)	76 (9.5%)	11 (6.7%)	23 (6.0%)	39 (6.9%)	17 (8.0%)	5 (11.9%)

**Table 8: Bivariate and Multivariate Association of LBDs and WBV for Cohort 1**

Variables	Any Symptoms (N=1070*)				Interrupting Symptoms (N=1070*)			
	Bivariate		Adjusted model*		Bivariate		Adjusted model*	
	RR	95%CI	RR	95%CI	RR	95%CI	RR	95%CI
<b>Age</b>								
< = 19 (ref)	1.00				1.00			
20-39	<b>2.04</b>	<b>1.34-3.11</b>	<b>1.82</b>	<b>1.18-2.80</b>	<b>2.77</b>	<b>1.01-7.60</b>	2.03	0.78-5.26
40-55	<b>2.60</b>	<b>1.75-3.81</b>	<b>2.32</b>	<b>1.55-3.47</b>	<b>3.53</b>	<b>1.37-9.06</b>	<b>2.66</b>	<b>1.09-6.44</b>
56-75	<b>2.50</b>	<b>1.68-3.72</b>	<b>2.22</b>	<b>1.48-3.34</b>	<b>3.15</b>	<b>1.20-8.25</b>	2.36	0.95-5.89
76+	1.17	0.59-2.29	1.03	0.50-2.11	1.30	0.25-6.69	0.58	0.07-4.71
<b>Gender</b>								
Female (ref)	1.00				1.00			
Male	<b>1.16</b>	<b>1.05-1.28</b>			1.25	0.98-1.61		
<b>Education</b>								
Less than high sch. (ref)	1.00				1.00			
Completed high sch.	<b>1.20</b>	<b>1.04-1.38</b>			1.36	0.96-1.92		
Completed university	<b>1.22</b>	<b>1.04-1.42</b>			1.17	0.78-1.75		
Inst. other than above	1.17	0.99-1.38			1.13	0.77-1.66		
<b>Operate tractor hrs/yr</b>								
None (ref)	1.00				1.00			
1-150	<b>1.29</b>	<b>1.10-1.51</b>	<b>1.23</b>	<b>1.05-1.44</b>	<b>1.66</b>	<b>1.12-2.46</b>	<b>1.55</b>	<b>1.05-2.30</b>
151-400	<b>1.42</b>	<b>1.22-1.65</b>	<b>1.32</b>	<b>1.14-1.54</b>	<b>1.65</b>	<b>1.08-2.53</b>	1.49	0.98-2.26
401+	<b>1.47</b>	<b>1.27-1.72</b>	<b>1.34</b>	<b>1.15-1.56</b>	<b>2.15</b>	<b>1.43-3.21</b>	<b>1.92</b>	<b>1.29-2.86</b>
<b>Operate combine hrs/yr</b>								
None (ref)	1.00				1.00			
1-60	1.11	0.97-1.28			1.23	0.86-1.77		
61-150	<b>1.25</b>	<b>1.10-1.41</b>			1.05	0.72-1.52		
151+	<b>1.29</b>	<b>1.14-1.45</b>			<b>1.64</b>	<b>1.19-2.24</b>		
<b>Operate ATV days/yr</b>								
None (ref)	1.00				1.00			
1-20	1.12	0.98-1.28			1.07	0.76-1.52		
21-80	1.10	0.94-1.28			1.18	0.80-1.74		
81+	<b>1.21</b>	<b>1.05-1.40</b>			1.43	0.98-2.10		

**Table 9: Bivariate and Multivariate Association of LBDs and WBV for Cohort 2**

Variables	Any Symptoms		Adjusted Model	Interrupting Symptoms	
	Bivariate ( N=200) RR	95%CI		Bivariate (N=499) RR	95%CI
<b>Age</b>					
<= 50	1.00			1.00	
51-60	1.07	0.97-1.19		0.99	0.97-1.01
61+	1.10	0.97-1.18		0.98	0.96-1.00
<b>Sex</b>					
Female	1.00			1.00	
Male	0.99	0.92-1.06		0.99	0.97-1.01
<b>Education</b>					
Less than high school	1.00			1.00	
Completed high school	0.92	0.84-1.00		1.02	0.99-1.05
Completed University	0.94	0.85-1.03		0.99	0.97-1.03
Institution other than above	0.94	0.87-1.02		1.01	0.98-1.04
<b>Tractor operation hrs/year</b>					
None	1.00			1.00	
1-250	1.01	0.90-1.12		0.99	0.97-1.03
251+	1.05	0.97-1.13		1.00	0.97-1.03
<b>Combine operation hrs/year</b>					
None	1.00			1.00	
1-120	1.00	0.92-1.09		0.98	0.97-1.01
121+	1.02	0.93-1.11		1.00	0.98-1.02
<b>ATV operation days/year</b>					
None	1.00			1.00	
1-60	0.97	0.90-1.04		0.98	0.96-1.00
61+	0.98	0.89-1.09		1.00	0.98-1.02
<b>Depression</b>					
No	1.00			1.00	
Yes	0.84	0.53-1.34		0.97	0.88-1.07
<b>Smoking</b>					
No	1.00			1.00	
Yes	1.07	0.96-1.19		1.01	0.97-1.04
<b>Height (Inches)</b>					
<=60	1.00			1.00	
61-65	<b>1.83</b>	<b>1.71-1.96</b>		1.05	0.93-1.19
66-70	<b>1.79</b>	<b>1.71-1.87</b>		1.04	0.92-1.17
71+	<b>1.74</b>	<b>1.62-1.86</b>		1.06	0.93-1.19
<b>BMI</b>					
Normal	1.00			1.00	
Overweight	1.02	0.94-1.10		0.99	0.97-1.01
Obese	0.99	0.90-1.08		0.97	0.95-1.00

Table 9 (continued)

<b>Weight (Pounds)</b>				
<=120	1.00		1.00	
121-160	0.99 0.84-1.18		0.98 0.97-1.00	
161-190	0.97 0.82-1.15		<b>0.98 0.97-0.99</b>	
191+	0.95 0.80-1.13		<b>0.97 0.96-0.99</b>	
<b>Heavy lifting days/year</b>				
None	1.00		1.00	
1-10	1.02 0.95-1.09		0.99 0.97-1.02	
11-50	0.88 0.78-1.00		0.98 0.96-1.01	
>50	0.94 0.83-1.05		0.98 0.95-1.01	
<b>Shoveling days/year</b>				
None	1.00		1.00	
1-10	1.08 1.01-1.15		1.02 0.99-1.04	
11-20	1.04 0.92-1.17		1.00 0.97-1.04	
>20	0.89 0.78-1.01		0.99 0.96-1.02	
<b>Hands above days/year</b>				
None	1.00		1.00	
1-5	0.99 0.91-1.08		0.99 0.97-1.02	
6-16	1.01 0.92-1.11		0.98 0.95-1.01	
>16	0.92 0.80-1.87		0.99 0.96-1.02	

**Table 10: Bivariate and Multivariate Association of Hip symptoms and WBV for Cohort 1**

Variables	6-YEAR FOLLOW-UP N*=1070					
	Any Hip Symptoms			Interrupting Hip Symptoms		
	Bivariate		Adjusted model*		Bivariate	
	RR	95%CI	RR	95% CI	RR	95%CI
<b>Age</b>						
< = 19 (ref)	1.00				1.00	
20-39	<b>2.61</b>	<b>1.15-5.94</b>	2.16	0.96-4.85	1.00	0.97-1.02
40-55	<b>5.28</b>	<b>2.55-10.94</b>	<b>4.14</b>	<b>1.99-8.62</b>	<b>0.97</b>	<b>0.95-0.99</b>
56-75	<b>5.05</b>	<b>2.42-10.50</b>	<b>4.13</b>	<b>1.98-8.60</b>	<b>0.97</b>	<b>0.94-0.99</b>
76+	<b>3.06</b>	<b>1.16-8.07</b>	<b>3.35</b>	<b>1.32-8.51</b>	1.01	1.00-1.03
<b>Gender</b>						
Female (ref)	1.00				1.00	
Male	<b>0.82</b>	<b>0.70-0.95</b>	<b>0.55</b>	<b>0.44-0.69</b>	1.02	1.00-1.04
<b>Education</b>						
Less than high sch. (ref)	1.00				1.00	
Completed high sch.	1.20	0.97-1.49			0.99	0.97-1.01
Completed university	1.12	0.87-1.44			1.01	0.99-1.03
Inst. other than above	1.11	0.86-1.43			0.99	0.97-1.02
<b>Operate tractor hrs/yr</b>						
None (ref)	1.00				1.00	
1-150	1.09	0.86-1.37	1.22	0.97-1.54	1.00	0.97-1.02
151-400	<b>1.31</b>	<b>1.03-1.65</b>	<b>1.95</b>	<b>1.45-2.62</b>	1.00	0.98-1.03
401+	1.19	0.94-1.52	<b>1.79</b>	<b>1.32-2.45</b>	1.00	0.98-1.02
<b>Operate combines hrs/yr</b>						
None (ref)	1.00				1.00	
1-60	0.90	0.71-1.15			1.00	0.98-1.03
61-150	0.93	0.74-1.18			1.02	1.00-1.04
151+	1.03	0.82-1.29			1.01	0.99-1.03
<b>Operate ATV hrs/yr</b>						
None	1.00				1.00	
1-20	0.86	0.68-1.09			0.98	0.96-1.00
21-80	1.03	0.80-1.33			1.00	0.98-1.02
81+	1.09	0.84-1.41			1.00	0.97-1.02

**Table 11: Bivariate and Multivariate Association of Hip Symptoms and WBV for Cohort 2**

Variables	Any Hip Symptoms			Interrupting Hip Symptoms		
	Bivariate RR	( N=388) 95%CI	Adjusted Model	Bivariate (N=562) RR	95%CI	Adjusted Model
<b>Age</b>						
<= 50	1.00			1.00		
51-60	0.99	(0.96-1.03)		0.99	(0.98-1.01)	
61+	0.96	(0.93-1.00)		0.99	(0.98-1.00)	
<b>Sex</b>						
Female	1.00			1.00		
Male	1.02	(0.97-1.06)		1.01	(0.99-1.03)	
<b>Education</b>						
Less than high school	1.00			1.00		
Completed high school	1.01	(0.96-1.07)		1.00	(0.98-1.01)	
Completed University	0.99	(0.93-1.06)		0.99	(0.97-1.00)	
Institution other than above	1.00	(0.94-1.06)		0.97	(0.96-1.01)	
<b>Tractor operation hrs/year</b>						
None	1.00			1.00		
1-250	1.03	(0.98-1.10)		1.00	(0.98-1.05)	
251+	1.04	(0.97-1.11)		1.02	(0.99-1.05)	
<b>Combine operation hrs/year</b>						
None	1.00			1.00		
1-120	1.03	(0.99-1.08)		1.00	(0.99-1.02)	
121+	1.03	(0.98-1.10)		1.01	(0.99-1.03)	
<b>ATV operation days/year</b>						
None	1.00			1.00		
1-60	1.00	(0.97-1.04)		1.00	(0.99-1.02)	
61+	0.97	(0.92-1.02)		0.98	(0.96-1.01)	
<b>Depression</b>						
No	1.00			1.00		
Yes	1.01	(0.92-1.11)		0.99	(0.94-1.04)	
<b>Smoking</b>						
No	1.00			1.00		
Yes	0.96	(0.89-1.04)		0.98	(0.97-1.03)	
<b>Height (Inches)</b>						
<=60	1.00			1.00		
61-65	1.28	(0.98-1.67)		1.03	(0.94-1.14)	
66-70	1.27	(0.97-1.70)		1.04	(0.95-1.15)	
71+	1.25	(0.96-1.64)		1.04	(0.93-1.15)-	
<b>BMI</b>						
Normal	1.00			1.00		
Overweight	1.02	(0.98-1.06)		0.99	(0.98-1.01)	
Obese	0.98	(0.93-1.03)		1.00	(0.98-1.02)	

**Table 11 (Continued)**

<b>Weight (Pounds)</b>				
<=120	1.00		1.00	
121-160	1.10 (0.91-1.35)		0.98 (0.96-0.99)	
161-190	1.12 (0.92-1.36)		0.99 (0.97-1.00)	
191+	1.09 (0.90-1.34)		0.99 (0.98-1.00)	
<b>Heavy lifting days/year</b>				
None	1.00		1.00	
1-10	1.04 (1.00-1.08)		1.01 (0.99-1.02)	
11-50	1.01 (0.95-1.06)		1.02 (1.00-1.03)	
>50	0.99 (0.94-1.05)		1.00 (0.97-1.02)	
<b>Shoveling days/year</b>				
None	1.00		1.00	
1-10	1.03 (0.99-1.07)		1.01 (0.99-1.02)	
11-20	0.94 (0.86-1.02)		1.00 (0.97-1.03)	
>20	1.01 (0.96-1.06)		1.01 (0.99-1.03)	
<b>Hands above days/year</b>				
None	1.00		1.00	
1-5	1.02 (0.98-1.06)		1.01 (0.99-1.03)	
6-16	1.04 (0.99-1.08)		1.01 (0.99-1.02)	
>16	0.96 (0.90-1.02)		1.00 (0.98-1.03)	

## 4.5 Discussion

The present study analysed two cohorts to investigate the relationship between farm machinery use and both hip and back symptoms. Cohort 1 found that tractor operation was consistently related to low back disorders and hip symptoms, with the strongest association between tractor operation and LBDs. All-terrain vehicles and combines showed some significant contribution to LBDs at certain exposure ranges, but the risk was less than that of operating tractors and did not persist after accounting for potential confounders. In addition, a stronger association was found with “Any symptoms” than “Interrupting symptoms” for both back and hip. Cohort 2 found no significant association with any farm machinery (tractor, combine and ATV) and either LBDs and hip symptoms. This is likely due to power limitations, as there was substantial loss to follow-up and those who reported LBDs from baseline were excluded from the analysis of cohort 2.

### 4.5.1 Challenges in Defining LBD cases

As described above, cohort 2 suffered a decreased sample size due to excluding those who reported symptoms at baseline. In order to ascertain the true incidence in a prospective cohort, a study must consider only new cases in the susceptible portion of the sample [46]. However, ascertaining incident cases of LBP is challenging. Besides LBP having a very high lifetime prevalence (84%) [47], it is commonly a recurrent condition [48, 49] and often chronic [49], making a true determination of incidence difficult. As reported by Duthey, “estimating the incidence of low back pain is difficult, as the incidence of first-ever episodes of low back pain is already high by early adulthood and symptoms tend to recur over time” [50]. As a result, Beaudet notes that “the difficulty in identifying the onset of low back pain limits the capacity to



determine the incidence of LBP” [51]. It has been projected that 25% of individuals with episode of LBD can experience recurrence within a year [52]. Although selecting LBP-free participants for 6-12 months prior to a study has been suggested [51], Beaudet is of the view that the set period is inadequate to “exclude recurrent patients having experienced previous LBP episodes and might results in a misclassification bias” [51]. Elders et al. also found that period of recall and duration of the investigation are important predictors of incidence and recurrence of LBP [53]. In light of this, it seems likely that eliminating those reporting symptoms in the 12 months prior to baseline dose not eliminate all those who have suffered back pain; it is possible it has little impact on the final results apart from limiting sample size. An NIH task group recently published a set of recommendations to help standardize the definition of chronic low back pain [54]. However, this was published after the present data was collected and even the new recommendations cannot change the issues of very high prevalence, early onset, and recurrence.

Due to the absence of symptom data at baseline, cohort 1 analyses were based on the assumption that MSK symptoms at baseline were negligible. This is clearly at odds with ample evidence showing high prevalence of low back pain in the general population [55] and farmers in particular [2]. However, given the present data limitations, not to mention the complexity of distinguishing true incidence from recurrence/chronicity, this assumption was necessary.

Cohorts 1 and 2 provide different types of evidence, but also represent a trade-off between different advantages and disadvantages. Although cohort 1 has the strength of a large sample size and a longer follow-up, there may be issues with misclassification of disease status since

the outcome status was not assessed at baseline. In contrast, cohort 2 is a true prospective study with the capacity to provide strong evidence on causality [46, 56], but had limited power due to sample size inadequacy (N=200). In this study with about 79% loss to follow up and 53% reporting symptoms at baseline, in order to identify a risk difference of 1.5 between highest and lowest exposure categories at a p=80% level, cohort 2 would need 925 eligible participants at follow up (equivalent to 9371 participants at baseline).

#### **4.5.2 Farm machinery use related to WBV**

Bovenzi et al. (OR =1.84, 95% CI 1.05-3.24) [57] and Bernard et al. (OR=1.44, 95% CI 1.15-1.80) [58]. The present study findings in cohort 1 (RR=1.23, 95% CI 1.05-1.44), (RR= 1.32, 95% CI 1.14-1.54), and (RR=1.34, 95% CI 1.15-1.56) were similar to findings in the previous studies [57-60]. Gomez et al. found a positive association between lower back trouble and intensity of tractor driving (OR= 1.51, 95% CI 1.20-1.89) [59]. Similarly, Hartman et al. found a positive association of exposure to 500h/year and above of WBV and back disorder (OR=1.71, 95% CI 1.08-2.71) [61]. However, the design and measure of association used by the present study characterized the strength of findings. Most of these previous studies that found association between WBV and LBDs involved cross-sectional designs [58, 59], and therefore had limitations in assessing temporal causality [62], as well, they lack the property of collapsibility [63] because they were based on odds ratios.

The present study findings were based on relative risk, which, due to its collapsibility property, keeps it size constant if a non-confounding variable is adjusted for [64]. For example, work conducted by Jewell found that after a non-confounding variable is controlled for, the relative risk (RR) was 2.0 across the two stratified levels of the non-confounding variable [65] (Jewell

2003, section 8.4 and table 8.6). Meanwhile the same data produced odds ratios of 2.43 and 2.16 for the two-levels of the non-confounding variable [66].

In the present study, a positive bivariate association was found between WBV and LBDs in farmers exposed to combine operation for 61 hours/year and above (RR=1.25, 95%CI =1.10-1.41), (RR=1.29, 95%CI 1.14-1.45). This is the first study known to the authors to investigate LBDs and combine-use.

Several previous studies have not found a relationship between LBDs and WBV among farmers [67, 68]. For example, both Toren et al. [69] and Hathorn et al.[70] found no relationship between tractor use and LBDs with effect estimates (OR=0.92, 95%CI 0.82-1.03) and (OR=1.35, 95%CI 0.86-2.11) respectively. Suggested reasons for not finding association include low response rate, recall bias [67], and sample size inadequacy [68]. Reasons for not finding association by these previous studies include low response rate, recall bias [67] and sample size inadequacy [68]. In terms of ATV operation, previous studies have not found an association between WBV from ATV and LBDs [71, 72]. Milosavljevic et al. [71] stated the reason for not finding an association can be in part attributed to sample size limitations; the authors suggested the use of larger samples in future studies to investigate this association further [71]. Rehn's [72] cross sectional study adjusted for several potential confounding variables including age, smoking, and job strain, and found no association between ATV operation and LBDs. The present study's finding on ATV was similar to these earlier studies [71, 72]; although, there was a positive bivariate association between farmers exposed to ATV for 81+ days/year and LBDs (RR = 1.21, 95% CI 1.05-1.40), after accounting for potential confounding variables this association did not persist.

#### 4.5.3 Symptoms in the hip and lower limb

LBDs may manifest as referred pain in the hip [23], and leg [24]. Hip [21], knee and ankle symptoms, which may be associated with LBDs or “sciatica” [73, 74], were therefore also investigated by the present study. Farmer participants with back pain were 33 times more likely to develop hip pain than those without back pain. Those with back pain were also 2.2 times likely to experience knee pain and 2.3 times likely to suffer from ankle pain than those without back pain. In the present cohort 1, some exposure categories of farm machinery use were association with WBV and hip symptoms in the bivariate results. However, after accounting for potential confounders, the only significant association was for tractor operation of 151 hours/year and above ( $RR = 1.95$ , 95% CI 1.45-2.62) and ( $RR = 1.79$ , 95% CI 1.32-2.45). A combined outcome of concurrent low back and hip symptoms yielded the strongest association with tractor operation for 151-400 hours/year after adjusting for potential confounders ( $RR=1.37$ , 95%CI 1.05-1.78). This is consistent with previous studies, where associations have been found between tractor operation and hip symptoms [59, 69, 75] after adjusting for potential confounders. In the present study, only a bivariate association was found between tractor operation for 401 hours/year and above ( $RR=1.36$ , 95%CI 1.09-1.69) and knee symptoms, and this association did not persist after adjustment for confounders. However, since the present study used the Standardized Nordic Questionnaire (SNQ) to assess musculoskeletal symptoms, the findings cannot decisively confirm the association found in the knee as a referred pain; the nature of the SNQ items is not specific for referred nerve pain, making it difficult to distinguish between referred pain and other mechanisms such as knee osteoarthritis. This observation has also been made by Suri et al. in a study of LBP in individuals

with knee symptomatic osteoarthritis: “true knee pain may also be confused with referred pain from the spine such as in the case of nerve root impingement and radiculopathy” [73]. The present results reinforce the previously reported result of increased hip symptoms, but do not provide evidence of increased referred pain in the lower limb with increased tractor use. Hip symptoms were not found to be significantly associated with any of the three farm machinery types (tractor, combine and ATV).

#### **4.5.4 Considering the biopsychosocial model**

LBDs are affected by many factors, not only physical exposures or risk factors. According to Pincus et al. “the biopsychosocial model of back pain has become a dominant model in the conceptualization of the etiology and prognosis of back pain” [29]. This model covers factors that could biologically, psychologically, and socially [29] influence LBDs. For example, depression [76] and smoking [77-79] have shown to be associated with back pain-related disability. Hence the present study considered the biopsychosocial model by investigating several demographic, psychosocial, environmental, and work-related factors which have been consistently found to be important in the development of LBDs [80]. Upon all the potential confounding variables investigated, only age was found to be a confounder in the primary relationship between WBV and LBDs in cohort 1. As well, no interactions were found in cohort 1. There are additional biopsychosocial variables not accounted for in this study. Kumar et al. observed that “several confounding factors make it difficult to determine the relation between back problems and WBV” [81], and the author suggested an example of such a factor to include poor working conditions and sitting for long periods [81]; Kumar further suggested that these potential confounders be accounted for in a high-quality study. Sprigg et al. noted that job-

related strain, for example job-related anxiety was related to LBDs [82]. Lis et al. found awkward posture to relate to LBDs [83]. Marras found bending and twisting as related to LBDs [84]. That these factors were not either captured by either cohorts 1 or 2, is a limitation and a consideration for future studies.

#### **4.5.5 Strengths and Limitations**

This is the first study to investigate the association between WBV and LBDs using two study designs; a prospective cohort design and a cross-sectional design with asynchronous recording of exposure and health outcome. These two study designs each have complementary strengths and limitations, which combine to provide evidence on the relationship between WBV and LBDs. The exposure measurement included several types of machinery and the questions were pilot tested. Also, several confounders were assessed in the present study especially in the cohort 2. Outcomes were measured using standardized, validated [85] musculoskeletal questions from the Standardized Nordic Questionnaire, which has successfully been applied in a similar study [57]. In terms of analysis techniques, the present study used one of the most appropriate statistical approaches found to produced relative risk estimates directly, consistently, and efficiently [86]. The study is the first to use prospective cohort design in farming to identify a relationship between LBDs and machinery use. The prospective cohort design employed in cohort 2 addresses temporality issues previously identified to be a limitation in this line of research [18].

This present study also had some limitations. Although it is a strength that the self-reported exposure questions were piloted, this method is not as precise as it could be if they were directly measured with accelerometers [87]. In addition, missing data due to loss to follow-up

or non eligibility were a major challenge, especially in cohort 2. Another limitation was that several potential confounding variables were not captured in cohort 1. Therefore, a full application and investigation of the biopsychosocial model was not possible with the larger sample in cohort 1.

#### **4.6 Conclusion**

Results of cohort 1 showed that after adjusting for potential confounders, longer annual tractor operation and older age are important predictors of lower back disorders in farmers. All-terrain vehicles and combines also showed some significant contribution to lower back disorders at certain exposure ranges, but the risk was less than that of operating tractors and did not persist after adjusting for confounders. Cohort 1 found that longer annual tractor operation and older age were also associated with hip symptoms. However, cohort 2, which used a prospective design known for providing the strongest evidence on causality, found no association between WBV and LBDs. Future prospective cohort studies with larger sample size and longer follow-up are needed to investigate this association further.

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## 4.8 References

1. Marras, W., *Occupational low back disorder causation and control*. Ergonomics, 2000. **43**(7): p. 880-902.
2. Holmberg, S., et al., *Musculoskeletal symptoms among farmers and non-farmers: a population-based study*. International journal of occupational and environmental health, 2002. **8**(4): p. 339-345.
3. Zhao, W., *Preventing Low Back Pain in Agriculture*. Rutgers NJAES Cooperative Extension. <https://njaes.rutgers.edu/pubs/publication.asp?pid=FS661>. 1992.
4. Borenstein, D., "Low Back Pain," in Barker LR, Burton JR (eds):. *Principles of Ambulatory Medicine*. 1991.
5. Goglia, V., et al., *Hand-transmitted vibration from the steering wheel to drivers of a small four-wheel drive tractor*. Applied ergonomics, 2003. **34**(1): p. 45-49.
6. Boshuizen, H.C., P.M. Bongers, and C.T. Hulshof, *Self-reported back pain in tractor drivers exposed to whole-body vibration*. International archives of occupational and environmental health, 1990. **62**(2): p. 109-115.
7. Cvetanovic, B. and D. Zlatkovic, *Evaluation of wholebody vibration risk in agricultural tractor drivers*. Bulgarian Journal of Agricultural Science, 2013. **19**(5): p. 1155-1160.
8. Manchikanti, L., *Epidemiology of low back pain*. Pain physician, 2000. **3**(2): p. 167-192.
9. Chen, J.-C., et al., *Using" exposure prediction rules" for exposure assessment: an example on whole-body vibration in taxi drivers*. Epidemiology, 2004. **15**(3): p. 293-299.
10. Varghese, M., et al. *A biomechanical and MRI analysis of back pain among drivers exposed to tractor vibrations*. in *2000 International Conference on the Biomechanics of Impact*. 2001. International Research Council on the Biomechanics of Impact BRON Cedex,, France.
11. Bovenzi, M., et al., *An epidemiological study of low back pain in professional drivers*. Journal of Sound and Vibration, 2006. **298**(3): p. 514-539.
12. WorkSafeBC, *WorkSafeBC Evidence-Based Practice Group 2008*. [http://www.worksafebc.com/health\\_care\\_providers/Assets/PDF/whole\\_body\\_vibration\\_low\\_back\\_pain.pdf](http://www.worksafebc.com/health_care_providers/Assets/PDF/whole_body_vibration_low_back_pain.pdf).
13. Putz-Anderson, V., et al., *Musculoskeletal disorders and workplace factors*. A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati: National Institute for Occupational Safety and Health, 1997.
14. Palmer, K.T., et al., *Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey*. Occupational and Environmental Medicine, 2000. **57**(4): p. 229-236.



15. Palmer, K.T., et al., *Case-control study of low-back pain referred for magnetic resonance imaging, with special focus on whole-body vibration*. Scand J Work Environ Health, 2008. **34**(5): p. 364-373.
16. Waters, T., et al., *The impact of operating heavy equipment vehicles on lower back disorders*. Ergonomics, 2008. **51**(5): p. 602-636.
17. Carel Hulshof and B.V.v. Zanten, *Whole-body vibration and low-back pain : A review of epidemiologic studies*. Int Arch Occup Environ Health (1 987) 59:205-220, 1 987.
18. Essien, S.K., Trask, C., Khan, M.I, Bath, B., Boden, C., (submitted). *Association between whole body vibration and low back disorder in farmers: a systematic review*. 2015.
19. De Beeck, R.O. and V. Hermans, *work-related low back disorders*. Brussels: Institute for Occupational Safety and Health, 2000.
20. Frank, J.W., et al., *Disability resulting from occupational low back pain: Part II: What do we know about secondary prevention? A review of the scientific evidence on prevention after disability begins*. Spine, 1996. **21**(24): p. 2918-2929.
21. Harris-Hayes, M., S.A. Sahrmann, and L.R. Van Dillen, *Relationship between the hip and low back pain in athletes who participate in rotation-related sports*. Journal of sport rehabilitation, 2009. **18**(1): p. 60.
22. Rostocki, A., *Back and Hip Pain*. <http://www.cure-back-pain.org/back-and-hip-pain.html>. 2013, Cure-Back-Pain.Org.
23. Nikolajsen, L., et al., *Pain and somatosensory findings in patients 3 years after total hip arthroplasty*. European journal of pain, 2009. **13**(6): p. 576-581.
24. Schäfer, A., T. Hall, and K. Briffa, *Classification of low back-related leg pain—a proposed patho-mechanism-based approach*. Manual therapy, 2009. **14**(2): p. 222-230.
25. Thelin, A., *Work and health among farmers*. Scandinavian Journal of Social Medicine, 1980(Suppl. 22).
26. Lee, W.J., E.S. Cha, and E.K. Moon, *Disease prevalence and mortality among agricultural workers in Korea*. Journal of Korean medical science, 2010. **25**(Suppl): p. S112-S118.
27. Trask, C., Khan, M. I., Adebayo, O., Boden, C., Bath, B., *Who gets studied? Examining inequities in the low back disorder literature*. Accepted by Journal of Agromedicine., 2015.
28. Ahmadi, I., *Performance Assessment of a Tractor Driver Whole Body Vibration Measuring System*. World Applied Sciences Journal, 2013. **21**(11): p. 1583-1586.
29. Pincus, T., et al., *Twenty-Five Years With the Biopsychosocial Model of Low Back Pain—Is It Time to Celebrate? A Report From the Twelfth International Forum for Primary Care Research on Low Back Pain*. Spine, 2013. **38**(24): p. 2118-2123.
30. Pickett, W., et al., *Determinants of agricultural injury: a novel application of population health theory*. Injury prevention, 2010.

31. Waddell, G., *The Biopsychosocial Model. The Back Pain Revolution*. 2nd edition ed. 2004, Churchill Livingstone, Toronto, Canada.
32. Gatchel, R.J., et al., *The biopsychosocial approach to chronic pain: scientific advances and future directions*. Psychological bulletin, 2007. **133**(4): p. 581.
33. Kuorinka, I., et al., *Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms*. Applied ergonomics, 1987. **18**(3): p. 233-237.
34. Baron, S., T. Hales, and J. Hurrell, *Evaluation of symptom surveys for occupational musculoskeletal disorders*. American journal of industrial medicine, 1996. **29**(6): p. 609-617.
35. Descatha, A., et al., *Validity of Nordic-style questionnaires in the surveillance of upper-limb work-related musculoskeletal disorders*. Scandinavian journal of work, environment & health, 2007. **33**(1): p. 58.
36. Chen, W., et al., *Comparison of robustness to outliers between robust poisson models and log-binomial models when estimating relative risks for common binary outcomes: a simulation study*. BMC medical research methodology, 2014. **14**(1): p. 82.
37. Green, B.B., et al., *Patient ability and willingness to participate in a web-based intervention to improve hypertension control*. Journal of medical Internet research, 2011. **13**(1).
38. Kaufman, J.S. and S. Harper, *Deficiency of the Odds Ratio for Common Outcomes*. American Journal of Psychiatry, 2012. **169**(10): p. 1118-1118.
39. Pan, W., *Akaike's information criterion in generalized estimating equations*. Biometrics, 2001. **57**(1): p. 120-125.
40. Westgate, P.M., *Improving the correlation structure selection approach for generalized estimating equations and balanced longitudinal data*. Statistics in medicine, 2014. **33**(13): p. 2222-2237.
41. Shults, J. and J.M. Hilbe, *Quasi-Least Squares Regression*. 2014: CRC Press.
42. Tabachnick, B. and L. Fidell, *Logistic regression. Using Multivariate Statistics*. 4th ed. Boston, Mass: Allyn & Bacon, 2001: p. 517-581.
43. Hosmer, D.W. and S. Lemeshow, *Applied logistic regression*. Second Edition ed. 2000: John Wiley & Sons.
44. Devereux, J., I. Vlachonikolis, and P. Buckle, *Epidemiological study to investigate potential interaction between physical and psychosocial factors at work that may increase the risk of symptoms of musculoskeletal disorder of the neck and upper limb*. Occupational and environmental medicine, 2002. **59**(4): p. 269-277.
45. Rothman, K.J. and S. Greenland, *Modern epidemiology 1998*. Philadelphia: Lippincott-Raven.
46. Song, J.W. and K.C. Chung, *Observational studies: cohort and case-control studies*. Plastic and reconstructive surgery, 2010. **126**(6): p. 2234.

47. Balagué, F., et al., *Non-specific low back pain*. The Lancet, 2012. **379**(9814): p. 482-491.
48. Carey, T.S., et al., *Recurrence and care seeking after acute back pain: results of a long-term follow-up study*. Medical care, 1999. **37**(2): p. 157-164.
49. Von Korff, M., *Studying the natural history of back pain*. Spine, 1994. **19**(18): p. 2041S-2046S.
50. Duthey, B., *Background Paper 6.24 Low back pain*. 2013.
51. Beaudet, N., et al., *Improving the selection of true incident cases of low back pain by screening retrospective administrative data*. European Journal of Pain, 2014. **18**(7): p. 923-931.
52. Stanton, T.R., et al., *After an episode of acute low back pain, recurrence is unpredictable and not as common as previously thought*. Spine, 2008. **33**(26): p. 2923-2928.
53. Elders, L.A. and A. Burdorf, *Prevalence, incidence, and recurrence of low back pain in scaffolders during a 3-year follow-up study*. Spine, 2004. **29**(6): p. E101-E106.
54. Deyo, R.A., et al., *Report of the NIH Task Force on research standards for chronic low back pain*. Pain Medicine, 2014. **15**(8): p. 1249-1267.
55. Brennan, G., et al., *Lower back pain in physically demanding college academic programs: a questionnaire based study*. BMC musculoskeletal disorders, 2007. **8**(1): p. 67.
56. Carlson, M.D. and R.S. Morrison, *Study design, precision, and validity in observational studies*. Journal of palliative medicine, 2009. **12**(1): p. 77-82.
57. Bovenzi, M. and A. Betta, *Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress*. Applied ergonomics, 1994. **25**(4): p. 231-241.
58. Bernard, C., et al., *Biomechanical and psychosocial work exposures and musculoskeletal symptoms among vineyard workers*. Journal of occupational health, 2011. **53**(5): p. 297-311.
59. Gomez, M., et al., *An analysis of self-reported joint pain among New York farmers*. Journal of agricultural safety and health, 2003. **9**(2): p. 143-157.
60. Hartman, E., et al., *Exposure to physical risk factors in Dutch agriculture: Effect on sick leave due to musculoskeletal disorders*. International journal of industrial ergonomics, 2005. **35**(11): p. 1031-1045.
61. Hartman, E., et al., *Exposure to physical risk factors in Dutch agriculture: Effect on sick leave due to musculoskeletal disorders*. International journal of industrial ergonomics, 2005. **35**(11): p. 1031-1045.
62. Kestenbaum, B., *Epidemiology and biostatistics: an introduction to clinical research*. 2009: Springer Science & Business Media.
63. Zou, G. and A. Donner, *Extension of the modified Poisson regression model to prospective studies with correlated binary data*. Statistical methods in medical research, 2013. **22**(6): p. 661-670.

64. Cummings, P., *The relative merits of risk ratios and odds ratios*. Archives of pediatrics & adolescent medicine, 2009. **163**(5): p. 438-445.
65. Jewell, N.P., *Statistics for epidemiology*. 2003: CRC Press.
66. Palmer, T.M., *Extensions to Mendelian randomization*. 2009, University of Leicester.
67. Hathorn, D.C., et al., *Self-reported back pain among farm women in southeast Louisiana*. AAOHN journal: official journal of the American Association of Occupational Health Nurses, 2009. **57**(6): p. 232-238.
68. Boshuizen, H.C., C.T. Hulshof, and P.M. Bongers, *Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration*. International archives of occupational and environmental health, 1990. **62**(2): p. 117-122.
69. Toren, A., et al., *Tractor-driving hours and their relation to self-reported low-back and hip symptoms*. Applied Ergonomics, 2002. **33**(2): p. 139-146.
70. Hathorn, D.C., et al., *Self-reported back pain among farm women in southeast Louisiana*. AAOHN journal, 2009. **57**(6): p. 232-238.
71. Milosavljevic, S., et al., *Does daily exposure to whole-body vibration and mechanical shock relate to the prevalence of low back and neck pain in a rural workforce?* Annals of occupational hygiene, 2012. **56**(1): p. 10-17.
72. Rehn, B., et al., *Musculoskeletal symptoms among drivers of all-terrain vehicles*. Journal of sound and vibration, 2002. **253**(1): p. 21-29.
73. Suri, P., et al., *Low back pain and other musculoskeletal pain comorbidities in individuals with symptomatic osteoarthritis of the knee: data from the osteoarthritis initiative*. Arthritis care & research, 2010. **62**(12): p. 1715-1723.
74. Croft, P., K. Jordan, and C. Jinks, *"Pain elsewhere" and the impact of knee pain in older people*. Arthritis & Rheumatism, 2005. **52**(8): p. 2350-2354.
75. Xiao, H., et al., *Agricultural work and chronic musculoskeletal pain among Latino farm workers: the MICASA study*. American journal of industrial medicine, 2013. **56**(2): p. 216-225.
76. Clays, E., et al., *The impact of psychosocial factors on low back pain: longitudinal results from the Belstress study*. Spine, 2007. **32**(2): p. 262-268.
77. Heliövaara, M., *Risk factors for low back pain and sciatica*. Annals of Medicine, 1989. **21**(4): p. 257-264.
78. Biglarian, A., et al., *Low back pain prevalence and associated factors in Iranian population: findings from the national health survey*. Pain research and treatment, 2012. **2012**.
79. Shiri, R., et al., *The association between smoking and low back pain: a meta-analysis*. The American journal of medicine, 2010. **123**(1): p. 87. e7-87. e35.

80. Teschke, K., et al., *Whole Body Vibration and Back Disorders Among Motor Vehicle Drivers and Heavy Equipment Operators A Review of the Scientific Evidence*. Occupational Hygiene, 1999. **6**: p. 123.
81. Kumar, A., et al., *Effect of whole-body vibration on the low back: a study of tractor-driving farmers in north India*. Spine, 1999. **24**(23): p. 2506.
82. Sprigg, C.A., et al., *Work characteristics, musculoskeletal disorders, and the mediating role of psychological strain: a study of call center employees*. Journal of Applied Psychology, 2007. **92**(5): p. 1456.
83. Lis, A.M., et al., *Association between sitting and occupational LBP*. European Spine Journal, 2007. **16**(2): p. 283-298.
84. Marras, W.S., *The working back: a systems view*. 2008: John Wiley & Sons.
85. Porter, J. and D. Gyi, *The prevalence of musculoskeletal troubles among car drivers*. Occupational Medicine, 2002. **52**(1): p. 4-12.
86. Zou, G., *A modified poisson regression approach to prospective studies with binary data*. American journal of epidemiology, 2004. **159**(7): p. 702-706.
87. Winkel, Jørgen, and Svend erik Mathiassen. "Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations." *Ergonomics* 37.6 (1994): 979-988.

## **Chapter 5: General Discussion and Conclusion**

The focus of this thesis was investigating the association between WBV and LBDs among farmers in two manuscripts. Firstly, the association between WBV and LBDs in farmers was investigated through a systematic literature review which forms manuscript one. Secondly, manuscript two investigated the relationship between WBV exposure and LBDs through prospective cohort data collected by the Saskatchewan farm injury cohort.

### **5.1 Manuscript 1: a systematic review**

This manuscript focused on LBDs as an outcome which is highly prevalent in farmers compared to other occupations [1]. Among all risk factors that may influence LBDs, exposure to vibration has been found to be harmful, even being exposed to it for an hour [2]. Mayton et al. noted that farm tractor and other earth-moving machinery are among important sources of “some of the most common, prolonged and severe occupational exposures of vehicle vibration” that affects machinery operators [3]. This makes farm machinery operators potentially at higher risk. However, the causal relationship between WBV and LBDs is not clear. Hence, this manuscript investigated the causal relationship between LBDs and WBV in farmers through a systematic literature review.

This systematic review was carried out using groups of terms for two concepts: ‘farming’ and ‘low back disorder,’ searched in online databases including Medline, Web of Science, CINAHL, SCOPUS, and EMBASE. Screening, data extraction, and quality assessment was performed by two reviewers independently. The PICO framework was applied to provide a structure for the

systematic review [4, 5]. In terms of population, this review focused on adult farmers or agricultural workers globally, including both males and females. As mentioned in chapter 2, the focus of this review was not an intervention *per se* but rather exposure to WBV. However, Lichtenstein et al. suggested that, in the absence of intervention, exposure can be considered within the PICO framework [6]. Hence, the effects of WBV resulting from use of farm machinery or agricultural vehicles were investigated. Controls were considered to be those with no exposure or very low exposure to WBV. The outcome was low back disorders, which includes low back pain, back pain, and lumbago. In terms of type of study, a wide range of studies was captured in this review, including both observational studies and RTCs. No restriction on date of publication was applied and only English language studies were considered. Data extraction included items on: study design, sampling strategy, socio-demographics, and exposure dimensions.

The first manuscript identified 12 articles for the assessment of the association between WBV and LBDs. Four studies showed a positive association between WBV and LBDs, four studies showed no association between WBV and LBDs, and the remaining four studies showed inconsistent association between LBDs and WBV depending on the exposure categories. However, a definitive statement on the association between WBV and LBDs among farmers cannot be made, given the heterogeneity in both the study contexts and the results. Since farmers are uniquely exposed due to their occupational setting with respect to the level, duration and frequency of WBV exposures, it seems likely that the relationship between WBV and LBDs may be unique to this industry. However, results are consistent with previous reviews on the association between WBV and LBDs in other industries. Lings and Yde [7] review found

no definitive evidence to support the association between WBV and LBDs among mixed occupation group. However, the authors noted that for a definitive conclusion to be drawn “good prospective studies with repeated measurement of exposures and clear (outcome) definition” [7] are needed. Similarly, Bovenzi et al.’s review on WBV and LBP also found insufficient evidence of clear relationship between WBV and LBP disorders, and the authors similarly attributed the insufficient evidence to limitations of cross-sectional design [8]. Other previous reviews have likewise found insufficient evidence to establish that WBV was causally associated with LBP [9, 10]; these studies attributed the reasons to temporal limitations of cross-sectional studies [9, 10] and one urged future studies to investigate the biological plausibility of this association [10].

## **5.2 Methodological considerations**

### **5.2.1 Design and statistical procedure used by studies**

Different designs and statistical procedures were used by studies to ascertain the relationship between WBV and LBD. In terms of statistical procedure, ten studies [11-20] used odds ratio, one used p-value from chi-square test [21], and the remaining one used both relative risk and rate ratio [22]. However, these statistical tests are not equivalent in the information that they provide. Biostatistics literature has cautioned readers to recognize the difference between odds ratio and relative risk in terms of meaning and interpretation [23-25]. In addition, the collapsibility property in relative risk makes comparison between studies which used relative risk and odd ratio difficult [26]. The collapsibility property keeps the magnitude of the risk ratio relatively constant if a non-confounding variable is adjusted [26], but this is not the case for odds ratios. For example, work conducted by Jewell found that after a non-confounding



variable is controlled for, the relative risk (RR) was 2.0 across the two stratified-levels of the non-confounding variable [27] (Jewell 2003, section 8.4 and table 8.6). Meanwhile, the same data produced odds ratios of 2.43 and 2.16 for the two-levels of the non-confounding variable [28].

Nine of the included studies used confidence level of 95% [11-16, 18-20] and two studies used confidence level of 90% [17, 22]. Although unusual confidence intervals can be converted into more conventional 95% confidence intervals, one study did not specify [21]. Since measures of association used by studies included in the systematic review to quantify the relationship between WBV and LBDs were quite varied, a definitive conclusion on association was difficult. The forest plot (see figure 3 in chapter 2) showed a positive association between WBV and LBDs in four of the studies [12, 15, 21, 29], three did not show any significant association [14, 16, 30] and the remaining one showed a mixed association [19]. However, definitive conclusions based on the forest plot cannot be made, as some studies controlled for confounders while others did not. In addition, different design type used by studies also hindered the review from making an explicit statement on the association between WBV and LBDs, as most of the studies reviewed share the temporality limitation due to being cross-sectional [31]. Although the few retrospective cohort studies included in the review tended to show a relationship, future studies with a prospective cohort design can help elucidate this association further.

### **5.2.2 Outcome and exposure assessments used by studies**

In general, the precision of exposure assessment used by the studies reviewed was low; the majority of studies used self-report of WBV, a method which has been found to have low reliability and validity [32]. Bernard et al.'s review suggested that self-report to assess exposure

likely obscures association between WBV and back pain [33]. Although direct exposure measurements have been found to “provide more reliable data” [32] for occupational exposure assessment and also is the preferred choice for ergonomic evaluation, only four studies used direct measurement and tended to show a relationship. Direct exposure measurement via triaxial accelerometer and calculation of VDV is “more sensitive to impulsive vibration” [34], and “responds more readily to the shocks in a signal” [35, 36].

Both the definition of LBDs and prevalence of LBDs period varied across studies. The majority of studies used standardized questionnaires to assess LBDs. Such questionnaires’ reliability have been tested [37-40] and have been applied successfully in other related studies[41]; however, a standard questionnaire such as the SNQ has a limitation as it “does not grade incidence or severity of symptoms” [42]. In addition, few studies used clinical diagnosis obtained from examination to assess LBDs [14, 18, 21]. Also, prevalence of LBDs periods varied from 7 days to lifetime, with most of the studies reporting 12 months prevalence. Such heterogeneity in terms of statistical strategy, LBDs definition and prevalence periods, type of design and exposure assessment method found in studies made comparisons and synthesis difficult. Osborne et al.’s review observed a similar limitation: “one consequence of the study heterogeneity is results that are not generalizable” [43].

### 5.2.3 Risk of bias

Risk of bias (ROB) may be defined “as the risk of a systematic error or deviation from the truth, in results or inferences” [44]. Assessing risk of bias as part of a review has been found to be vital even when there exists “variability in either the results or the validity of the included studies” [45]. Risk of bias assessment of included studies also paves the way for evaluating the strength

of a body of evidence [46]. The assessment of the quality of the studies included in manuscript 1 was carried out with STROBE criteria [47] of study design, sample size, data source and method of assessment, sampling strategy, as well as, a back pain specific tool developed by Hoy et al. [48] to examine studies in terms of risk of bias (Appendix D & E).

Overall, assessment of quality of the included studies showed some consistent strong and weak points. Reporting non-response and random sampling were rated “no” for most included studies. Non-response bias, just like all other study biases, can pose a severe threat to validity of interpretation and generalization of results [49, 50]. Similarly, the “unique strength of randomization is that if successfully accomplished, it prevents selection bias” [51]. This suggests that if randomization is not performed in a study, it may introduce bias which can affect the validity of interpretation and generalization of results. Other risk of bias dimensions that most studies failed to meet included appropriate length of prevalence of LBDs period, and reporting appropriate numerators and denominators. Thus, some included studies estimated measures of association based on inappropriate numerators and denominators, which may be due to uncertainties in the data or data collection process. To improve the quality of studies, future studies should pay attention to performing and reporting an appropriate numerators and denominators as well as appropriate sampling strategies.

#### **5.2.4 Strengths and limitations**

The strength of the systematic review presented in this thesis is that it is the first time such a study on association between WBV and LBDs has been done in the high-risk group select population of farmers [52]. In terms of methodological strength, this review provided detailed information on exposure assessment and categories. Also, the search for studies for the

systematic review was done comprehensively and screened thoroughly to meet the inclusion criteria [53]. In addition, risk of bias for included studies was assessed with a published tool found to be reliable [48], as well as academic checklists for observational studies [47].

Manuscript 1 also had some limitations. Due to the low number of articles identified in this review, studies were not eliminated based on risk of bias assessment, as has been done in previous reviews [54]. This means that lower quality evidence was also included in the review. Glanville et al. noted that including lower quality studies in a review may lead to the “risk of providing unreliable results” [55]. However, manuscript 1 included all studies identified in the review because previous published reviews deemed it to be important to consider wide range of studies as “public health often draws upon diverse forms of evidence” [56, 57], making it problematic not to include lower quality studies based on ROB assessment. Also, since the review included only articles that were published in English language, study findings may be impacted by language bias. A recent English-language review of LBD among farmers discovered a bias towards developed nations disproportionate to the world’s agricultural workforce; a finding which may be related to language restrictions [58]. However, other previous reviews have found no impact of language restriction on systematic reviews [59, 60], although one review [59] did acknowledge the possibility of language bias.

### **5.3 Manuscript 2: a prospective cohort study**

The focus of this manuscript was to investigate the association between farming-related WBV and LBDs using data collected through the SFIC, a prospective cohort. Follow-up data on LBDs and related symptoms were collected during 2013 (cohort 1 with 6 years of follow-up) and

2014 (cohort 2 with 1 year of follow-up). This resulted in two datasets for each of two cohorts: cohort 1 with 1,149 farm people who had been followed for six years, and cohort 2 with 605 participants followed for 1 year. The key findings of manuscript two were that, after adjusting for potential confounders, cohort 1 found a positive association between all categories tractor operation and LBDs as described by “Any back symptoms”, and also categories 1-150 hours/year and 401+ hours/year related to “Interrupting back symptoms”. A dose-response relationship was found in annual accumulated hours of exposure to tractor operation and LBDs. In addition, tractor operation (for 151-400 hrs/year and 401+ hrs/year) was also found to be related to hip symptoms. Although combine operation  $\geq 61$  hrs/year and ATV operation  $\geq 81$  days/year were related to LBD in the bivariate analysis in cohort 1, this association did not persist after adjustment for confounders.

Although cohort 1 found associations, the results are likely to be prone to bias due to misclassification of disease status since the outcome status was not assessed at baseline. In addition, misclassification bias can also be encountered in cohort 2 (the ‘true’ prospective cohort study) which included only samples that reported LBP free for the short period of 12-months. This is because it is likely that eliminating those reporting symptoms in the 12 months prior to baseline does not eliminate all those who have ever suffered back pain. This has also been observed by Beaudet, who say that recruiting LBP-free participants for 6-12 months prior to a study is inadequate to “exclude recurrent patients having experienced previous LBP episodes and might results in a misclassification bias”[61]. This demonstrates how challenging it is to ascertain incident cases of LBP. According to Duthey, “estimating the incidence of low back pain is difficult, as the incidence of first-ever episodes of low back pain is already high by early

adulthood and symptoms tend to recur over time”[62]. Due to this, Beaudet notes that “ the difficulty in identifying the onset of low back pain limits the capacity to determine the incidence of LBP” [61]. In addition to the lifetime prevalence of LBP being very high (84%) [63], it is a commonly recurrent condition [64, 65] and often chronic [65], makes a true determination of incidence difficult. Cohort 2, which used a true prospective design known for providing the strongest evidence on causality, found no association between WBV and LBDs. This is likely due to power limitations, as there was substantial loss to follow-up and those who reported LBDs from baseline were excluded from the analysis of cohort 2.

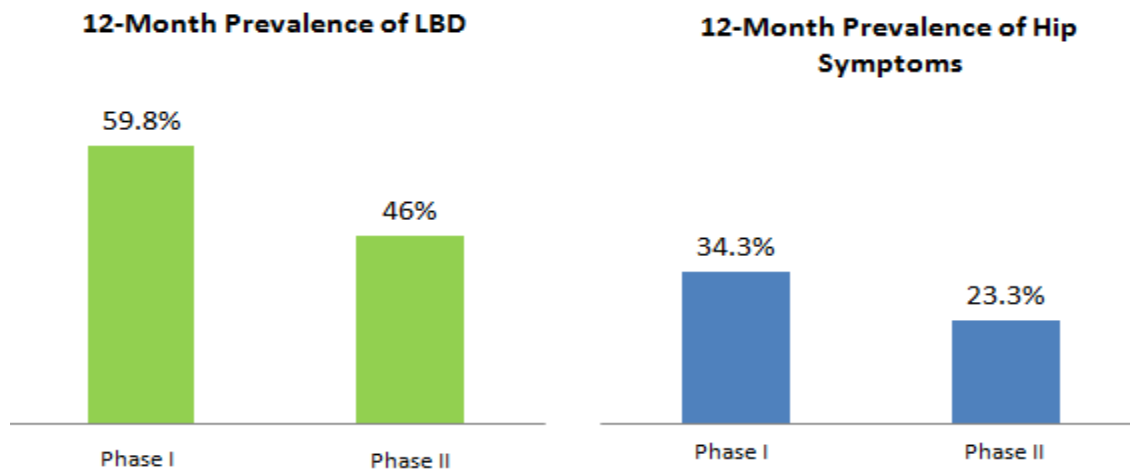
The findings from cohort 1 were consistent with earlier studies. Toren et al. found that tractor driving influence the risk of low-back symptoms [16]. Bovenzi et al. also found an increased risk of low-back symptoms in tractor driving [20]. Other previous studies also found association between tractor operation and LBDs [12, 21, 66]. Findings of cohort 1 also revealed that machinery type has an impact, as stronger effects were found in tractor operation than ATV and combine operation. The stronger association found by tractor operation may be attributable in part to frequency of its use on farms during the year, sample effect, and working conditions. Other farm machinery such as a combines are often used solely during the harvesting season. Although Rehn notes that characteristics of ATVs such as driving style and machine type makes it more vibration-prone vehicle compared to other vehicle types [42], the present study did not find any association between WBV from ATV use and LBDs after adjusting for confounders. Other previous studies also found no association between WBV from ATVs and LBD [11, 67]. In contrast, Futatsuka et al. found LBDs higher prevalence of LBDs in non-operator farmers than in operator farmers [68]; however, the authors added that determining

the exact health implications of WBV may be difficult, as LBDs may originate from many other causes such as working posture, operating heavy equipment, and in farm working conditions [68].

Since LBDs may manifest as referred pain in the hip [69], manuscript 2 also investigated the association between farming-related WBV and hip symptoms. After accounting for potential confounders, the only significant association in cohort 1 was found in tractor operation for 151 hours/year and above. This finding is consistent with earlier published studies. Toren et al. found that tractor driving increases the risk of hip symptoms [16]. Similarly, a 5-year prospective cohort study by Tuchsén et al. found WBV to be a strong predictor of hip pain [70], and Jacobsson et al. found increased risk of hip osteoarthritis with tractor driving [71].

### **5.3.1 Prevalence of the main outcomes**

The main study outcomes were: 1) trouble ('aches, pain, discomfort') in the lower back and hip/thighs and 2) trouble bad enough to limit work tasks. Manuscript 2 found higher 12-month prevalence for LBDs in cohort 1 (59.8%) than was found in cohort 2 (46.0%) (See figure 7). The 12-month prevalence for hip symptoms also revealed a similar pattern, with cohort 1 recording higher prevalence (34.3%) than in cohort 2 (23.3%) (See figure 7). This result was consistent with other LBD prevalence published in earlier studies. Toren et al. found 12-month prevalence of any low back symptoms (61%) and hip symptoms (33%) in Swedish farmers [16]. Other previous studies also found similar results on the 12-month prevalence for low back and hip symptoms [15, 19, 72].



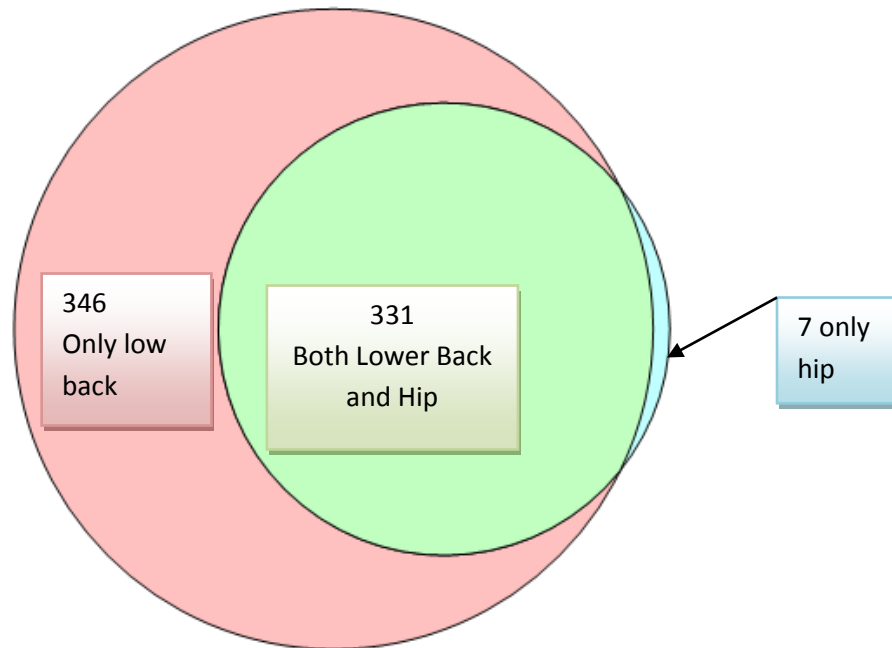
**Figure 7: 12-month prevalence of LBDs and hip symptoms**

### 5.3.2 Combined outcome of LBDs and hip

Research has shown that the hip cannot function independently of the lower back [73]. An example from sport biomechanics found that golfers with a history of LBP showed deficits in lead hip medial rotation range of motion [74]. This is due in part to the “anatomical proximity of the hip and lumbopelvic region” [75]. Hip pain may occur as a result of referred pain from LBDs [69] and may extend to the leg [76]. Also, reducing symptoms in the low back may reduce pain in the hip and enhance hip function [77]. Cohort 1 examined the relationship between WBV and farmer participants who reported both hip and lower back symptoms. The combined outcome of concurrent low back and hip symptoms found the strongest association with tractor operation for 151-400 hours/year after adjusting for potential confounders. Farmer participants with back pain were 33 times more likely to have hip pain than those without back pain (see figure 8). This result supports previously reported results on the connection between LBDs and



increased hip symptoms. Rostocki reports that “lower back and hip pains are often experienced together, making it a common combination symptom syndrome” [73].



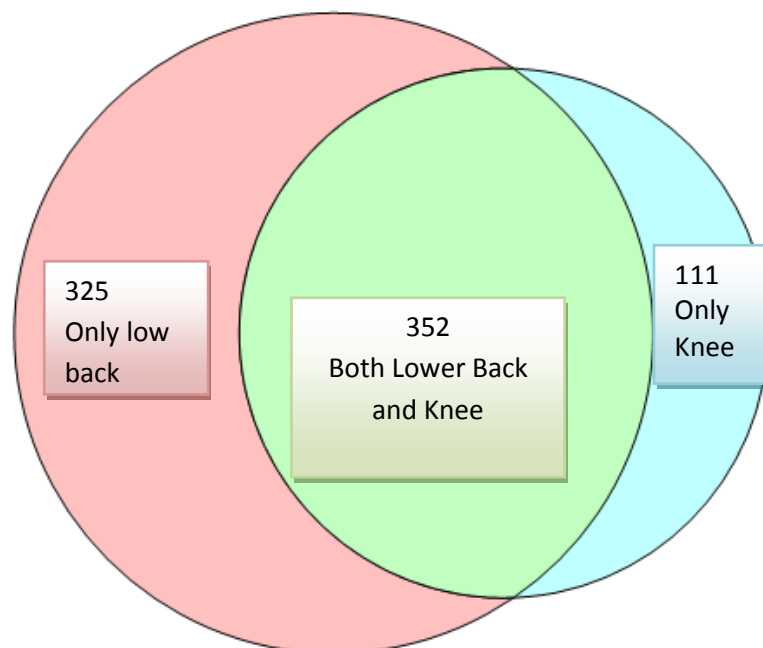
**Figure 8: Number of low back symptoms, hip symptoms, and coincidence of low back and hip symptoms**

### 5.3.3 Other lower limb outcome

In addition to the hip and back, manuscript 2 also investigated the relationship between WBV and other lower limb outcomes such as symptoms in the ankle/feet and the knees in cohort 1.

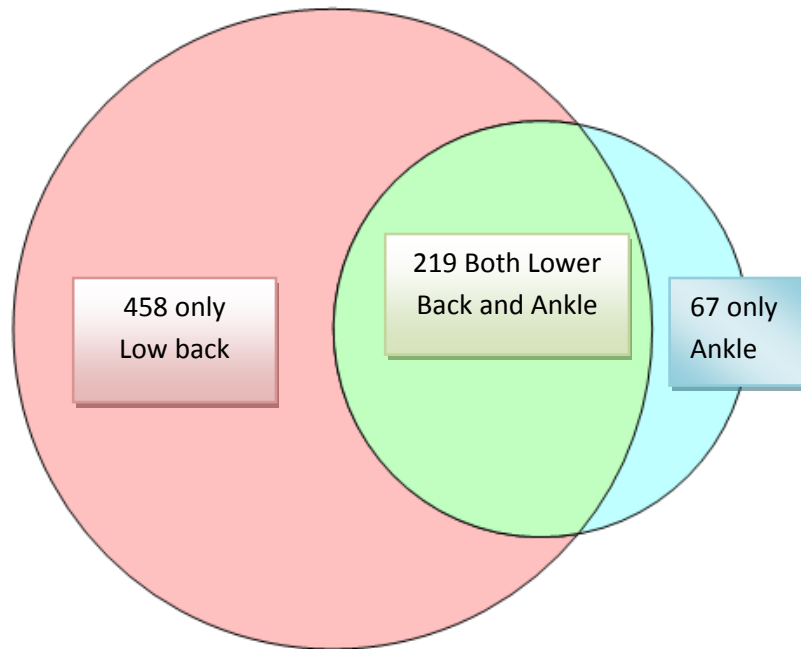
In terms of knee pain, farmer participants with back pain were 2.2 times likely to experience knee pain than those without back pain (See figure 9). The only bivariate significant association with knee pain as an outcome was found in tractor exposure for 401+ hours/year (RR=1.36, 95%CI 1.09-1.69). However, this association did not persist after adjusting for potential confounding variables.

Despite having back pain increases the risk of experiencing lower leg symptoms, it is difficult to confirm that this is due to referred pain. In the present study, the self-report tool used (SNQ) is not specific for referred nerve pain, so is not possible to definitively separate that from knee osteoarthritis or other types of localized knee pathology. Suri et al. also note that distinguishing between local knee pathology and referred pain from the spine may be challenging, particularly without a physical examination, especially in the case of “nerve root impingement and radiculopathy” [78].



**Figure 9: Number of low back symptoms, knee symptoms, and coincidence of low back and knee symptoms**

In terms of ankle symptoms, no association was found with operation of tractor, combine, or ATV. However, participants with back pain were 2.3 times likely to suffer from ankle pain than those without back pain (See figure 10).



**Figure 10: Number of low back symptoms, ankle symptoms, and coincidence of low back and ankle symptoms**

The findings of manuscript 2 do not support an association between WBV and lower limb (knee and ankle) pain. The hypothesis that referred pain would lead to a relationship between WBV and lower limb symptoms cannot be confirmed; it appears that pain reported by farmers in the lower limbs likely comes from other mechanisms.

#### **5.4 Methodological considerations**

Manuscript 2 has several methodological issues which bear consideration. These considerations include: bivariate correlation of independent variables; effect of clustering in both cohort 1 and cohort 2; outcome and exposure assessments; influence of other confounding factors; and other strengths and limitations.

#### 5.4.1 Bivariate correlation

The highest bivariate correlations were observed for gender and tractor operation ( $r=0.65$ ) in cohort 1 and between hands above shoulder and shoveling ( $r=0.64$ ) in cohort 2. The criterion cut-point used in this study for assessing highly correlated variables to avoid collinearity was ( $r > 0.7$ ). All correlations were below the cut-point and so none were eliminated.

#### 5.4.2 Clustering effect of cohort 1 and cohort 2

Since the data used for manuscript 2 had clustered grouping of farmer participants on the same farms, the effect of clustering was assessed in both cohorts. Clustering of farmers accounted for 18% of the variability in 'LBD any symptoms' in cohort 1, as determined by a significant random effect. Introduction of 'farm commodity' and 'operating arrangement' as fixed effects on farm did not account for the inter-farm variability in cohort 1. On the other hand, cohort 2 depicted a perfect Intra-cluster correlation (100%) as determined by a significant random effect. A 100 % Intra-cluster correlation means a perfect similarity of farmers clustered on one farm. Only 16 % of the variability in 'LBD any symptoms' within cohort 2 was accounted for by 'farm commodity' and 'operating arrangement' on farm (see results in Appendix C). If not accounted for properly in the analysis stage, these significant intracluster correlations (i.e. correlation within cluster) are likely to cause limitations including: under power of the study, type I error rate inflation [79-81]; and bias in the standard errors, "potentially resulting in misleading conclusion" [82]. However, the use of generalised estimating equations (GEEs) enabled the present study to properly account for clustering [83].

### 5.4.3 Measure of association

Manuscript 2 used relative risk as a measure of association to assess the relationship between WBV and LBDs in farmers. The modified Poisson regression enabled manuscript 2 to estimate the relative risk directly [84]. Both prevalence of lower back and hip symptoms met the rule of thumb for a common outcome (>10%) [85, 86], which made it possible for the study to estimate the relative risk directly. Although Skandfer et al. found the prevalence of LBP to be (51%); they found a limitation as to the use of odds ratio in estimating the risk, since “for frequently occurring outcomes, such as LBP, the revealed ORs can overestimate the magnitude of the risks” [41]. Furthermore, the size of a relative risk is kept fixed even if a variable which is not a confounder is adjusted due to its collapsibility property [26], However, odds ratio lacks this property [87].

### 5.4.4 Outcome and exposure assessments

As with all exposure-response studies the results of this study should be interpreted with consideration of the measurement for both the outcome and exposure. The Standardized Nordic Questionnaire (SNQ) has been found to be a useful tool for assessing musculoskeletal symptoms related to workplace ergonomics [37, 39]. The reliability and validity of the SNQ have been tested already and have also been found to be acceptable [37-40]. Previous evaluation of the SNQ using clinical examination as the reference method, found the sensitivity in a range of situations ranging from 82.3% to 100% and specificity from 51.1% to 82.4% [88]. Rehn notes a limitation of the SNQ as it “does not grade incidence or severity of symptoms” [42]. In addition, the present study results also highlight that the nature of the SNQ is not specific enough to differentiate pathoanatomical sources of pain or other symptoms such as neuropathic pain,

referred somatic pain from spinal structures or appendicular osteoarthritis (i.e. hip or knee joint).

In terms of the exposure assessment, the questionnaire has some limitations. Although the exposure questionnaire on WBV was put together by a panel of Agricultural Health and Safety Researchers [89] and was piloted on knowledgeable farm producers [89], it was not as precise as it could have been if WBV were directly measured [90]. As described in the introduction, direct measurement involves an electronic accelerometer being placed on the seat of the machinery/vehicle as described by ISO standards [91]. Also, the direct exposure approach has been found to be “more sensitive to impulsive vibration” [34]. Overall, the methods used were probably not as accurate as direct, but allowed for a large sample to be efficiently assessed [92].

#### **5.4.5 Considering the biopsychosocial model: influence of other factors**

LBDs are affected by factors in many dimensions besides physical exposure. Futatsuka et al. note that it is becoming difficult to “find out the health effects of whole body vibration itself” [68], as health effects may originate from many causes including working posture, operating heavy materials, and in farm working conditions [68]. McNamee notes that for causal studies, attention should be paid to potential confounding, since “it results in biased estimation of the exposure effect and may suggest a causal effect where none exists or that a true effect is hidden” [93]. Manuscript 2 accounted for several potential confounding variables, including non-driving farm task such as heavy lifting, shoveling and working with hands above shoulder; personal characteristics such as age, height and BMI; and farm characteristics such as commodity and operating arrangement. No interaction effects were found, but age was found

to be a confounder in cohort 1. However, the association between WBV and LBDs may not have persisted if other factors such as bending and twisting, job-related strain, and awkward posture were considered. Unfortunately, data on these potential confounders were not available in either cohort 1 or 2.

Although stress on the hip joint resulting from exposures such as heavy lifting have been found to be increased among farmers [71, 94, 95], the current study found no association between heavy lifting and hip symptoms. Similarly, Tüchsen et al. found BMI to be a significant risk factor for hip pain after adjusting for other factors [70]; however, the present study found no association between hip symptoms and BMI. Earlier studies have found job-related strain [96], awkward posture [97], and bending and twisting [98] to be related to LBDs. Alkherayf et al. found increased risk of LBP in young adults who smoke [99]; however the authors noted that the relationship between smoking and LBP is dose-dependent [99]. In contrast, the present study found no association between smoking and LBDs in cohort 2. Although not all possible confounders were assessed in the present study, several were available, particularly in the cohort 2. Compared to many prior studies on the topic of WBV and LBDs which do not account for any confounders, the present study represents advancement by considering an array of potential confounders within a biopsychosocial framework.

#### **5.4.6 Strengths and limitations**

Manuscript 2 makes a unique contribution to the literature by being the first study to investigate the association between WBV and LBDs using two study designs: a prospective cohort design and a cross-sectional design with asynchronous recording of exposure and health outcome. This study also used a standardized instrument for measuring LBDs; the reliability and

validity of the SNQ have been tested already and found to be acceptable for assessing musculoskeletal symptoms in the workplace [37-40]. In addition, the exposure measurement captured several types of farm machinery and the exposure questions were pilot tested on knowledgeable farm producers [89]. This manuscript used one of the most appropriate statistical approaches found to produced relative risk estimates directly, consistently, and efficiently [84]. Finally, cohort 2 was the first known prospective cohort design applied on this topic in farmers, so temporality issues identified as a limitation in earlier studies [100] were addressed.

Manuscript 2 also had some limitations. Missing data resulting from loss to follow-up or non-eligibility were a major shortcoming in this manuscript, especially in cohort 2. Undoubtedly, it was a strength that questions on exposure were piloted, however, self-report is not as precise as if exposures were directly measured [90]. Another limitation was that several potential confounding variables were not captured in cohort 1. Therefore, a full application and investigation of the biopsychosocial model was not possible with the larger sample provided by cohort 1.

## 5.5 Implications

Manuscript two demonstrated that after considering two study designs (a prospective cohort design and a cross-sectional design with asynchronous recording of exposure and health outcome), farmers exposed to tractor operation for longer yearly duration are at higher risk of experiencing LBDs as well as hip symptoms than knee and ankle symptoms; no such difference were found for ATV and combine use with cross-sectional design. However, no difference was



also observed in all three farm machinery (tractor, combine and ATV) with a prospective cohort design. Solecki noted that WBV in the agricultural sector arise from vehicle or machinery types such as “wheel-type agricultural tractors and self-propelled farm machines (e.g., combine harvesters)” [101]. In addition, Futatsuka et al. also observed that WBV on the seats of combine harvesters and wheel tractors exceeded the recommended ISO 2631 exposure limit [68]. Although some studies have previously been conducted on agricultural tractors and LBDs, no prior studies have been conducted between LBDs and WBV on combines making this is the first study to specifically investigate combines.

## **5.6 Practical Significance**

The findings of this thesis may have broader practical implications for occupations that use WBV-prone machinery, especially farmers. It will also be useful to agricultural safety specialists, occupational health and safety professionals, and clinicians in their day to day work. This may be achieved by reducing operators’ hours of exposure to tractors especially among those aged 40-75 years. In addition, the results of this thesis may help to inform governments, occupational health agencies, and other agricultural industry stakeholders to develop policies that promote safer working environments for farmers which would in turn limit pain, loss of productivity, and temporary or permanent disabilities. For example, policies or recommendations that set recommended upper limits on tractor usage may be helpful.

## **5.7 Implications and direction for future research**

Although both manuscripts have addressed gaps in knowledge regarding the association between WBV and LBDs, some gaps still remain for future research to address. Future research

should focus on more prospective cohort studies, LBDs definition standardization, and more consistent exposure metrics. Ultimately, a better understanding of the association of WBV and LBDs will assist in developing strategies to prevent and reduce pain, loss of productivity, temporary or permanent disabilities in farmers. Future research involving direct measurement can help identify appropriate prevention strategies.

## 5.8 Conclusions

Overall, reviewing published literature on the association between whole body vibration and lower back disorders in farmers showed that findings are inconclusive. Four studies showed no association between WBV and LBDs, four studies showed a positive association between WBV and LBDs, and four studies showed mixed association between LBDs and WBV depending on exposure categories by studies. Considerable heterogeneity in terms of inferential test, LBDs definition, type of commodity produced, and type of design, makes comparisons and synthesis difficult. Although retrospective cohort studies tended to show a relationship, studies with a prospective cohort design can help clarify this association further.

A cross-sectional investigation showed that after adjusting for potential confounders, longer annual tractor operation and older age are important predictors of lower back disorders in farmers. Other WBV sources such as all-terrain vehicles and combines also showed some significant contribution to lower back disorders at certain exposure ranges, but the risk was less than that of operating tractors and did not persist after adjusting for confounders. Also, longer annual tractor operation and older age were associated with hip symptoms. In contrast, a true

prospective design found no association between WBV and LBDs. However, this may be due to an under-powered sample in this cohort.

## 5.9 References

1. Holmberg, S., et al., *Musculoskeletal symptoms among farmers and non-farmers: a population-based study*. International journal of occupational and environmental health, 2002. **8**(4): p. 339-345.
2. Cvetanovic, B. and D. Zlatkovic, *Evaluation of wholebody vibration risk in agricultural tractor drivers*. Bulgarian Journal of Agricultural Science, 2013. **19**(5): p. 1155-1160.
3. Mayton, A., et al., *Jarring/jolting exposure and musculoskeletal symptoms among farm equipment operators*. International Journal of Industrial Ergonomics, 2008. **38**(9): p. 758-766.
4. Huang, X., J. Lin, and D. Demner-Fushman. *Evaluation of PICO as a knowledge representation for clinical questions*. in *AMIA annual symposium proceedings*. 2006. American Medical Informatics Association.
5. Davies, K.S., *Formulating the evidence based practice question: a review of the frameworks*. Evidence Based Library and Information Practice, 2011. **6**(2): p. 75-80.
6. Lichtenstein, A.H., E.A. Yetley, and J. Lau, *Application of Systematic Review Methodology to the Field of Nutrition: Nutritional Research Series, Vol. 1*. 2009.
7. Lings, S. and C. Leboeuf-Yde, *Whole-body vibration and low back pain: A systematic, critical review of the epidemiological literature 1992–1999*. International archives of occupational and environmental health, 2000. **73**(5): p. 290-297.
8. Bovenzi, M. and C. Hulshof, *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, 1999. **72**(6): p. 351-365.
9. WorkSafeBC, *WorkSafeBC Evidence-Based Practice Group 2008*.  
[http://www.worksafebc.com/health\\_care\\_providers/Assets/PDF/whole\\_body\\_vibration\\_low\\_back\\_pain.pdf](http://www.worksafebc.com/health_care_providers/Assets/PDF/whole_body_vibration_low_back_pain.pdf).
10. Waters, T., et al., *The impact of operating heavy equipment vehicles on lower back disorders*. Ergonomics, 2008. **51**(5): p. 602-636.

11. Milosavljevic, S., et al., *Does daily exposure to whole-body vibration and mechanical shock relate to the prevalence of low back and neck pain in a rural workforce?* Annals of occupational hygiene, 2012. **56**(1): p. 10-17.
12. Bernard, C., et al., *Biomechanical and psychosocial work exposures and musculoskeletal symptoms among vineyard workers.* Journal of occupational health, 2011. **53**(5): p. 297-311.
13. Hathorn, D.C., et al., *Self-reported back pain among farm women in southeast Louisiana.* AAOHN journal: official journal of the American Association of Occupational Health Nurses, 2009. **57**(6): p. 232-238.
14. Hartman, E., et al., *Risk factors for sick leave due to musculoskeletal disorders among self-employed Dutch farmers: A case-control study.* American journal of industrial medicine, 2006. **49**(3): p. 204-214.
15. Gomez, M., et al., *An analysis of self-reported joint pain among New York farmers.* Journal of agricultural safety and health, 2003. **9**(2): p. 143-157.
16. Toren, A., et al., *Tractor-driving hours and their relation to self-reported low-back and hip symptoms.* Applied ergonomics, 2002. **33**(2): p. 139-146.
17. Boshuizen, H.C., P.M. Bongers, and C.T. Hulshof, *Self-reported back pain in tractor drivers exposed to whole-body vibration.* International archives of occupational and environmental health, 1990. **62**(2): p. 109-115.
18. Hartman, E., et al., *Exposure to physical risk factors in Dutch agriculture: Effect on sick leave due to musculoskeletal disorders.* International journal of industrial ergonomics, 2005. **35**(11): p. 1031-1045.
19. Xiao, H., et al., *Agricultural work and chronic musculoskeletal pain among Latino farm workers: the MICASA study.* American journal of industrial medicine, 2013. **56**(2): p. 216-225.
20. Bovenzi, M. and A. Betta, *Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress.* Applied ergonomics, 1994. **25**(4): p. 231-241.
21. Kumar, A., et al., *Effect of whole-body vibration on the low back: a study of tractor-driving farmers in north India.* Spine, 1999. **24**(23): p. 2506.

22. Boshuizen, H.C., C.T. Hulshof, and P.M. Bongers, *Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration*. International archives of occupational and environmental health, 1990. **62**(2): p. 117-122.
23. Viera, A.J., *Odds ratios and risk ratios: what's the difference and why does it matter?* Southern medical journal, 2008. **101**(7): p. 730-734.
24. Bland, J.M. and D.G. Altman, *The odds ratio*. Bmj, 2000. **320**(7247): p. 1468.
25. Holcomb Jr, W.L., et al., *An odd measure of risk: use and misuse of the odds ratio*. Obstetrics & Gynecology, 2001. **98**(4): p. 685-688.
26. Cummings, P., *The relative merits of risk ratios and odds ratios*. Archives of pediatrics & adolescent medicine, 2009. **163**(5): p. 438-445.
27. Jewell, N.P., *Statistics for epidemiology*. 2003: CRC Press.
28. Palmer, T.M., *Extensions to Mendelian randomization*. 2009, University of Leicester.
29. Hartman, E., et al., *Exposure to physical risk factors in Dutch agriculture: Effect on sick leave due to musculoskeletal disorders*. International journal of industrial ergonomics, 2005. **35**(11): p. 1031-1045.
30. Hathorn, D.C., et al., *Self-reported back pain among farm women in southeast Louisiana*. AAOHN journal, 2009. **57**(6): p. 232-238.
31. Song, J.W. and K.C. Chung, *Observational studies: cohort and case-control studies*. Plastic and reconstructive surgery, 2010. **126**(6): p. 2234.
32. David, G., *Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders*. Occupational medicine, 2005. **55**(3): p. 190-199.
33. Bernard, B., V. Putz-Anderson, and S. Burt, *A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*. Cincinnati: Centers for Disease Control and Prevention National Institute for Occupational Safety and Health publication, 1997: p. 97-141.
34. Blood, R., et al., *Whole body vibration exposures in metropolitan bus drivers: A comparison of three seats*. Journal of Sound and Vibration, 2010. **329**(1): p. 109-120.

35. Bust, P.D., *Contemporary Ergonomics 2008: Proceedings of the International Conference on Contemporary Ergonomics (CE2008), 1-3 April 2008, Nottingham, UK*. 2008: CRC Press.
36. Newell, G., N.J. Mansfield, and L. Notini, *Survey of heavy equipment operators whole-body vibration profiles*. Contemporary Ergonomics, 2008. **2008**: p. 203.
37. Kuorinka, I., et al., *Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms*. Applied ergonomics, 1987. **18**(3): p. 233-237.
38. Porter, J. and D. Gyi, *The prevalence of musculoskeletal troubles among car drivers*. Occupational Medicine, 2002. **52**(1): p. 4-12.
39. Baron, S., T. Hales, and J. Hurrell, *Evaluation of symptom surveys for occupational musculoskeletal disorders*. American journal of industrial medicine, 1996. **29**(6): p. 609-617.
40. Dickinson, C., et al., *Questionnaire development: an examination of the Nordic Musculoskeletal Questionnaire*. Applied ergonomics, 1992. **23**(3): p. 197-201.
41. Skandfer, M., et al., *Low back pain among mineworkers in relation to driving, cold environment and ergonomics*. Ergonomics, 2014. **57**(10): p. 1541-1548.
42. Rehn, B., *Musculoskeletal disorders and whole-body vibration exposure among professional drivers of all-terrain vehicles*. <http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A142690&dswid=-7187>, in Umeå University medical dissertations, ISSN 0346-6612 ; 852. 2004.
43. Osborne, A., et al., *Risk factors for musculoskeletal disorders among farm owners and farm workers: A systematic review*. American journal of industrial medicine, 2012. **55**(4): p. 376-389.
44. *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0*. In: Higgins JPT, Green S, eds. *The Cochrane Collaboration*; 2011.
45. *Assessing risk of bias in included studies*. <http://bmq.cochrane.org/assessing-risk-bias-included-studies>.
46. Viswanathan, M., et al., *Assessing the risk of bias of individual studies in systematic reviews of health care interventions*. 2012.

47. Von Elm, E., et al., *The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies*. Preventive medicine, 2007. **45**(4): p. 247-251.
48. Hoy, D., et al., *Assessing risk of bias in prevalence studies: modification of an existing tool and evidence of interrater agreement*. Journal of clinical epidemiology, 2012. **65**(9): p. 934-939.
49. Leadbetter, S., et al., *Peer Reviewed: Recruiting Women for a Study on Perceived Risk of Cancer: Influence of Survey Topic Salience and Early Versus Late Response*. Preventing chronic disease, 2013. **10**.
50. Mazor, K.M., et al., *A demonstration of the impact of response bias on the results of patient satisfaction surveys*. Health services research, 2002. **37**(5): p. 1403-1417.
51. Higgins, J., Green S. *Cochrane handbook for systematic reviews of interventions Version 5.1. 0 [updated March 2011]. The Cochrane Collaboration, 2011. www.cochrane-handbook.org*, 2014.
52. Driscoll, T., et al., *The global burden of occupationally related low back pain: estimates from the Global Burden of Disease 2010 study*. Annals of the rheumatic diseases, 2014. **73**(6): p. 975-981.
53. *PROSPERO (CRD42014013247).Centre for Reviews and Dissemination website*.
54. Burström, L., T. Nilsson, and J. Wahlström, *Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis*. International archives of occupational and environmental health, 2014: p. 1-16.
55. Glanville, J., et al., *A review of the systematic review process and its applicability for use in evaluating evidence for health claims on probiotic foods in the European Union*. Nutrition Journal, 2015. **14**(1): p. 16.
56. Katikireddi, S.V., M. Egan, and M. Petticrew, *How do systematic reviews incorporate risk of bias assessments into the synthesis of evidence? A methodological study*. Journal of epidemiology and community health, 2015. **69**(2): p. 189-195.



57. Ogilvie, D., et al., *Systematic reviews of health effects of social interventions: 2. Best available evidence: how low should you go?* Journal of epidemiology and community health, 2005. **59**(10): p. 886-892.
58. Trask, C., Khan, M. I., Adebayo, O., Boden, C., Bath, B. , (2015) *Who gets studied? Examining inequities in the low back disorder literature. Journal of Agromedicine.* 20:273–281
59. Morrison, A., et al., *The effect of English-language restriction on systematic review-based meta-analyses: a systematic review of empirical studies.* International journal of technology assessment in health care, 2012. **28**(02): p. 138-144.
60. Pham, B., et al., *Language of publication restrictions in systematic reviews gave different results depending on whether the intervention was conventional or complementary.* Journal of Clinical Epidemiology. **58**(8): p. 769-776.e2.
61. Beaudet, N., et al., *Improving the selection of true incident cases of low back pain by screening retrospective administrative data.* European Journal of Pain, 2014. **18**(7): p. 923-931.
62. Duthey, B., *Background Paper 6.24 Low back pain.* 2013.
63. Balagué, F., et al., *Non-specific low back pain.* The Lancet, 2012. **379**(9814): p. 482-491.
64. Carey, T.S., et al., *Recurrence and care seeking after acute back pain: results of a long-term follow-up study.* Medical care, 1999. **37**(2): p. 157-164.
65. Von Korff, M., *Studying the natural history of back pain.* Spine, 1994. **19**(18): p. 2041S-2046S.
66. Varghese, M., et al. *A biomechanical and MRI analysis of back pain among drivers exposed to tractor vibrations.* in *2000 International Conference on the Biomechanics of Impact.* 2001. International Research Council on the Biomechanics of Impact BRON Cedex,, France.
67. Rehn, B., et al., *Musculoskeletal symptoms among drivers of all-terrain vehicles.* Journal of sound and vibration, 2002. **253**(1): p. 21-29.
68. Futatsuka, M., et al., *Whole-body vibration and health effects in the agricultural machinery drivers.* Industrial health, 1998. **36**(2): p. 127-132.

69. Nikolajsen, L., et al., *Pain and somatosensory findings in patients 3 years after total hip arthroplasty*. European journal of pain, 2009. **13**(6): p. 576-581.
70. Tüchsen, F., et al., *Risk factors predicting hip pain in a 5-year prospective cohort study*. Scandinavian journal of work, environment & health, 2003: p. 35-39.
71. Jacobsson, B., N. Dalen, and B. Tjörnstrand, *Coxarthrosis and labour*. International orthopaedics, 1987. **11**(4): p. 311-313.
72. Gupta, G., *Prevalence of Musculoskeletal Disorders in Farmers of Kanpur-Rural, India*. Journal of Community Medicine & Health Education, 2013.
73. Rostocki, A., *Back and Hip Pain*. <http://www.cure-back-pain.org/back-and-hip-pain.html>. 2013, Cure-Back-Pain.Org.
74. Murray, E., et al., *The relationship between hip rotation range of movement and low back pain prevalence in amateur golfers: an observational study*. Physical Therapy in Sport, 2009. **10**(4): p. 131-135.
75. Harris-Hayes, M., S.A. Sahrmann, and L.R. Van Dillen, *Relationship between the hip and low back pain in athletes who participate in rotation-related sports*. Journal of sport rehabilitation, 2009. **18**(1): p. 60.
76. Schäfer, A., T. Hall, and K. Briffa, *Classification of low back-related leg pain—a proposed patho-mechanism-based approach*. Manual therapy, 2009. **14**(2): p. 222-230.
77. Stupar, M., et al., *The association between low back pain and osteoarthritis of the hip and knee: a population-based cohort study*. Journal of manipulative and physiological therapeutics, 2010. **33**(5): p. 349-354.
78. Suri, P., et al., *Low back pain and other musculoskeletal pain comorbidities in individuals with symptomatic osteoarthritis of the knee: data from the osteoarthritis initiative*. Arthritis care & research, 2010. **62**(12): p. 1715-1723.
79. Preisser, J.S., et al., *The importance and role of intracluster correlations in planning cluster trials*. Epidemiology (Cambridge, Mass.), 2007. **18**(5): p. 552.
80. Donner, A. and N. Klar, *Design and analysis of cluster randomization trials in health research*. 2000.

81. Murray, D.M., *Design and analysis of group-randomized trials*. Vol. 29. 1998: Oxford University Press.
82. Norton, E.C., et al., *Analysis of prevention program effectiveness with clustered data using generalized estimating equations*. Journal of Consulting and Clinical Psychology, 1996. **64**(5): p. 919.
83. Yelland, L.N., A.B. Salter, and P. Ryan, *Performance of the modified Poisson regression approach for estimating relative risks from clustered prospective data*. American journal of epidemiology, 2011: p. kwr183.
84. Zou, G., *A modified poisson regression approach to prospective studies with binary data*. American journal of epidemiology, 2004. **159**(7): p. 702-706.
85. Chen, W., et al., *Comparison of robustness to outliers between robust poisson models and log-binomial models when estimating relative risks for common binary outcomes: a simulation study*. BMC medical research methodology, 2014. **14**(1): p. 82.
86. Greenland, S., *Interpretation and choice of effect measures in epidemiologic analyses*. American journal of epidemiology, 1987. **125**(5): p. 761-768.
87. Zou, G. and A. Donner, *Extension of the modified Poisson regression model to prospective studies with correlated binary data*. Statistical methods in medical research, 2013. **22**(6): p. 661-670.
88. Descatha, A., et al., *Validity of Nordic-style questionnaires in the surveillance of upper-limb work-related musculoskeletal disorders*. Scandinavian journal of work, environment & health, 2007. **33**(1): p. 58.
89. Pickett, W., et al., *Determinants of agricultural injury: a novel application of population health theory*. Injury prevention, 2010.
90. Winkel, Jørgen, and Svend erik Mathiassen. "Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations." *Ergonomics* 37.6 (1994): 979-988.
91. ISO, 1997. "Evaluation of human exposure to whole body vibration". International Organization for Standardization. Ref. No. ISO 2631-1.

92. Hardt, J.S., et al., *A comparison of exposure assessment approaches: lung cancer and occupational asbestos exposure in a population-based case–control study*. Occupational and environmental medicine, 2013: p. oemed-2013-101735.
93. McNamee, R., *Regression modelling and other methods to control confounding*. Occupational and environmental medicine, 2005. **62**(7): p. 500-506.
94. Croft, P., et al., *Osteoarthritis of the hip and occupational activity*. Scandinavian journal of work, environment & health, 1992: p. 59-63.
95. Thelin, A., *Work and health among farmers*. Scandinavian Journal of Social Medicine, 1980(Suppl. 22).
96. Sprigg, C.A., et al., *Work characteristics, musculoskeletal disorders, and the mediating role of psychological strain: a study of call center employees*. Journal of Applied Psychology, 2007. **92**(5): p. 1456.
97. Lis, A.M., et al., *Association between sitting and occupational LBP*. European Spine Journal, 2007. **16**(2): p. 283-298.
98. Marras, W.S., *The working back: a systems view*. 2008: John Wiley & Sons.
99. Alkherayf, F. and C. Agbi, *Cigarette smoking and chronic low back pain in the adult population*. Clinical & Investigative Medicine, 2009. **32**(5): p. 360-367.
100. Essien, S.K., Trask, C., Khan, M.I, Bath, B., Boden, C., (submitted). *Association between whole body vibration and low back disorder in farmers: a systematic review*. 2015.
101. Solecki, L., *Studies of farmers' annual exposure to whole body vibration on selected family farms of mixed production profile*. Annals of Agricultural and Environmental Medicine, 2012. **19**(2).

## Appendix A: Ethics Approval



UNIVERSITY OF  
SASKATCHEWAN

Behavioural Research Ethics

### Certificate of Approval

PRINCIPAL INVESTIGATOR  
James A. Douran

DEPARTMENT  
Canadian Centre for Health and Safety in Agriculture 14-242

REB#

INSTITUTION(S) WHERE RESEARCH WILL BE CONDUCTED  
University of Saskatchewan

SUB-INVESTIGATOR(S)  
Louise Hagel

STUDENT RESEARCHER(S)  
Samuel Kwaku Essien

FUNDER(S)  
CANADIAN INSTITUTES OF HEALTH RESEARCH (CIHR)

#### TITLE

Association Between Whole Body Vibration and Low Back Disorder Among Saskatchewan Farmers

ORIGINAL REVIEW DATE  
26-Jun-2014

APPROVAL ON  
26-Jun-2014

APPROVAL OF:  
APPLICATION FOR BEHAVIORAL  
RESEARCH ETHICS REVIEW  
Secondary Analysis of Existing Data

EXPIRY DATE  
25-Jun-2015

Full Board Meeting ☐

Delegated Review ☒

#### CERTIFICATION

The University of Saskatchewan Behavioural Research Ethics Board has reviewed the above-named research project. The proposal was found to be acceptable on ethical grounds. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project, and for ensuring that the authorized research is carried out according to the conditions outlined in the original protocol submitted for ethics review. This Certificate of Approval is valid for the above time period provided there is no change in experimental protocol or consent process or documents.

Any significant changes to your proposed method, or your consent and recruitment procedures should be reported to the Chair for Research Ethics Board consideration in advance of its implementation.

#### ONGOING REVIEW REQUIREMENTS

In order to receive annual renewal, a status report must be submitted to the REB Chair for Board consideration within one month of the current expiry date each year the study remains open, and upon study completion. Please refer to the following website for further instructions: [http://www.usask.ca/research/ethics\\_review/](http://www.usask.ca/research/ethics_review/)

Beth Bilson, Chair  
University of Saskatchewan  
Behavioural Research Ethics Board

Please send all correspondence to:

Research Ethics Office  
University of Saskatchewan  
Box 5000 RPO University, 1602-110 Gymnasium Place  
Saskatoon SK S7N 4J8  
Telephone: (306) 966-2975 Fax: (306) 966-2959

## Appendix B: Main Exposure and Outcomes Questions

During 2012, how many hours per year did you:  
(If not applicable write "0")

B-17 Operate tractors? \_\_\_\_\_

B-18 Do routine maintenance on **tractors**? \_\_\_\_\_

B-19 Operate combines? \_\_\_\_\_

B-20 Do routine maintenance on **combines**? \_\_\_\_\_

During 2012, how many days per year did you:  
(If not applicable write "0")

B-21 Operate all-terrain vehicles? \_\_\_\_\_

B-34



	Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in:		Have you at any time in the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?	
	Yes	No	Yes	No
Neck	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
One or both shoulders	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
One or both elbows	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
One or both wrists/hands	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Upper back	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lower back	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
One or both hips/thighs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
One or both knees	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
One or both ankles/feet	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Appendix C: Output of Covariance Parameter Estimates for both Random and Fixed Effects

### Cohort 1

Covariance Parameter Estimates							
Cov Parm	Subject	Estimate	Standard Error	Z Value	Pr > Z	Wald 95% Confidence Bounds	
Intercept	farmcode2007	0.04200	0.009604	4.37	<.0001	0.02809	0.06963
Residual		0.1975	0.01117	17.68	<.0001	0.1773	0.2214

### Cohort 2

Covariance Parameter Estimates							
Cov Parm	Subject	Estimate	Standard Error	Z Value	Pr > Z	Wald 95% Confidence Bounds	
Intercept	farmcode2013	0.03851	0.005880	6.57	<.0001	0.02926	0.05333
Residual		0.2096	0.007144	29.34	<.0001	0.1963	0.2243

## Appendix D: Quality Assessment Tool Adapted from Hoy et al. (2012)

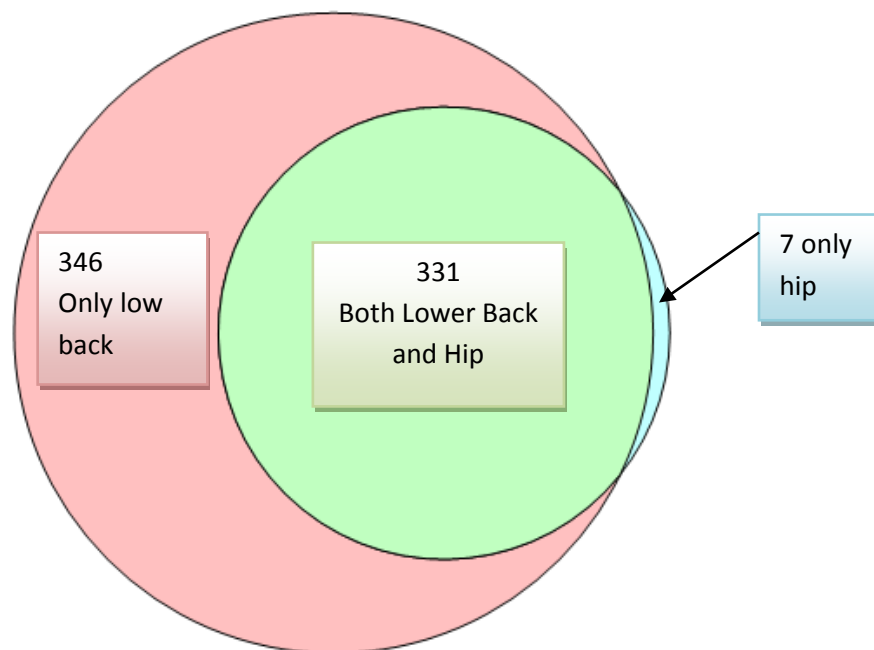
Risk of Bias Questions	Response	Origin	Notes/Modification
1) Was the sampling frame a true or close representation of the target population?	Binary (Yes/No)	Hoy	N/A
2) Was some form of random selection used to select the sample, OR, was a census undertaken?	Binary (Yes/No)	Hoy	N/A
3) Was the likelihood of nonresponse bias minimal?	Binary (Yes/No)	Hoy	N/A
4) Were data collected directly from the subjects (as opposed to a proxy)?	Binary (Yes/No)	Hoy	N/A
5) Was an acceptable case definition used in the study?	Binary (Yes/No)	Hoy	N/A
6) How was the quality of LBD definition captured?	Scale (1, low 5, high)	Hoy	Modification
7) Was the study instrument that measured the parameter of interest (e.g. prevalence of LBD) shown to have reliability and validity (if necessary)?	Binary (Yes/No)	Hoy	N/A
8) Was the same mode of data collection used for all subjects?	Binary (Yes/No)	Hoy	N/A
9) Was the length of the shortest prevalence period for the parameter of interest appropriate?	Binary (Yes/No)	Hoy	N/A
10) Were the numerator (s) and denominator (s) for the parameter of interest appropriate?	Binary (Yes/No)	Hoy	N/A



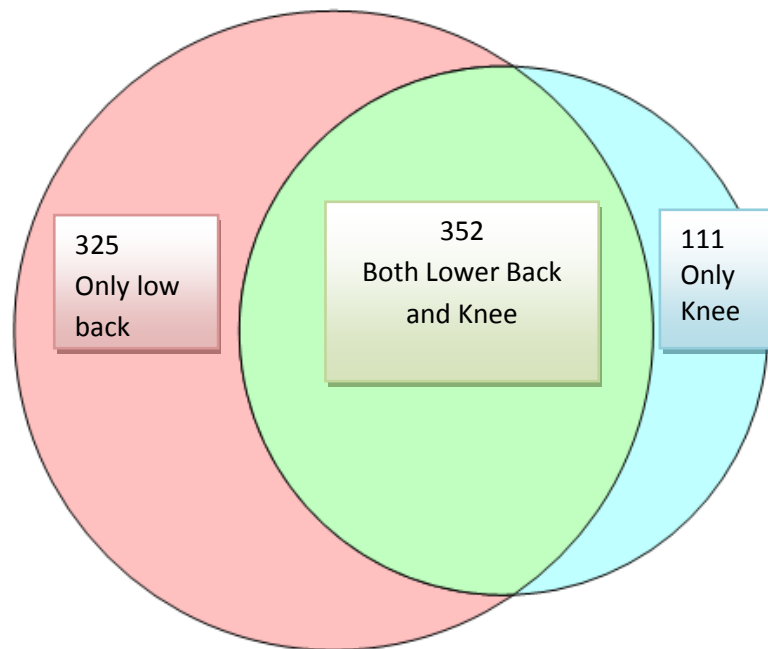
## Appendix E: Other Modified Questions Adapted from STROBE Statement

Questions	Description
1) What statistical methods were used?	Reported statistical methods used by the author (s). Example: logistic regression, discriptives, correlations, etc
2) What is the significance level and confidence interval associated with this risk factor?	Reported CIs OR p-value. Example: CIs or p-value of adjusted (multivariate) model or in the absence of multivariate, Univariate model.
3) How these risk factors supported by the study findings?	Conclusion about the risk factors by the author (s). Example: significant positive relationship, negative, or not significant.
4) Were confounding variables controlled?	If multivariate analysis, what confounders were included? Example: age, sex, etc.

## Appendix F: Number of Low back Symptoms, Hip Symptoms, and Coincidence of Low Back and Hip Symptoms



## Appendix G: Number of Low back Symptoms, Knee Symptoms, and Coincidence of Low Back and Knee Symptoms



## Appendix H: Number of Low back Symptoms, Ankle Symptoms, and Coincidence of Low Back and Ankle Symptoms

