

Original Article

A Randomized Controlled Trial of a Truck Seat Intervention: Part 2—Associations Between Whole-Body Vibration Exposures and Health Outcomes

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Submitted 17 July 2017; revised 13 April 2018; editorial decision 6 June, 2018; revised version accepted 12 June 2018.

Abstract

This randomized controlled trial study was conducted to determine whether two different seating interventions would reduce exposure to whole-body vibration (WBV) and improve associated health outcomes. Forty professional truck drivers were randomly assigned to two groups: (i) a control group of 20 drivers who received a new, industry-standard air-suspension seat, and (ii) an intervention group of 20 drivers who received an active-suspension seat. This study collected regional body pain (10-point scale), low back disability [Oswestry Disability Index (ODI)], physical and mental health [the Short Form 12-item Health Survey (SF-12)], and work limitations [Work Limitation Questionnaire (WLQ)] before and 3, 6, and 12 months after the seating intervention. WBV exposures were also collected during the same time periods. Due to dropouts at the 12-month time period, only data up to 6 months post-intervention were included in the analyses. The post-intervention A(8) WBV exposures were lower in both groups with a more substantial WBV exposure reduction (~50%) in the intervention group compared to the control group (~26%). There was little to no change in the impulsive exposures [VDV(8) and $S_{ed}(8)$] post-intervention and no differences between the two groups. The self-reported musculoskeletal health outcomes showed that intervention group experienced a greater reduction in the low back pain (LBP) and other musculoskeletal outcomes than the control group. The LBP reduction in the intervention group was clinically meaningful (>25%); however, none of the changes in pain reached statistical significance (P 's > 0.22). The SF-12 health scores demonstrated

that the intervention group's physical health improved after the intervention (P 's < 0.06) while the control group experience little to no improvement (P 's > 0.11). The WLQ scores showed that the intervention group generally experienced reduced (improved) work limitation over time whereas the control group showed inconsistent changes in work limitation scores. These study findings indicate that reducing truck drivers' exposure to WBV through seating intervention can lead to improvements in LBP and other health outcomes.

Keywords: disability index; low back pain; SF-12 health survey; Work Limitation Questionnaire; work-related musculoskeletal disorders

Introduction

Previous studies have shown that truck drivers, especially long haul drivers, suffer from a great deal of health issues including work-related musculoskeletal disorders (WMSDs) with over three times higher injury rates than the private industry average (Rauser et al., 2008; Rauser et al., 2014; Smith and Williams, 2014). In addition, professional drivers report a significantly greater median number of days away from work (17 days) due to occupational injuries and illness compared to workers in private industry (8 days). Among these injuries and illnesses, WMSDs are the single largest component accounting for 41% of claims cost in the trucking sector in Washington State, USA (Rauser et al., 2008; Rauser et al., 2014).

Among WMSDs, low back pain (LBP) accounts for 20% of all US workers' compensation claims and is responsible for 33–46% of all workers' compensation costs which estimates range from 45 to 54 billion dollars annually in the USA (Webster and Snook, 1994; Anderson, 1998; Leigh, 2011; Marcum and Adams, 2017). As LBP is one of the most significant non-lethal medical conditions (Marras, 2000), it often results in persistent disability that can create a substantial economic burden and lost productivity in the workplace (Punnett et al., 2005; Ammendolia et al., 2009).

Whole-body vibration (WBV) is one of the leading risk factors for the development of low back disorders and other general adverse health outcomes among professional drivers (Troup, 1988; NIOSH, 1997; Teschke et al., 1999). Previous epidemiological and physiological studies have consistently shown a strong association between occupational WBV exposure and LBP in professional vehicle drivers with a clear dose–response relationship (Pope, 1991; Bovenzi, 1996; Bernard, 1997; Bovenzi and Hulshof, 1999; Bovenzi, 2009). Although exact injury mechanisms have not been fully understood, biomechanical studies found possible injury pathways including elevated spinal load (Fritz, 1997; Fritz, 2000), supporting musculature fatigue (Wilder et al., 1996), and damaged intervertebral discs (Griffin, 1990; Thalheimer, 1996; Aulck, 2012).

The extended driving hours (8–12 h/day and up to 70 h a week) in long-haul truck drivers increases the exposure to WBV and therefore create greater potential for adverse health outcomes. Teschke et al. (1999) showed that risks of injuries increased as the duration and dose of WBV increases. In fact, LBP prevalence in professional drivers has been estimated to range between 60–80% (Schwarze et al., 1998; Bovenzi et al., 2006; Bovenzi et al., 2009; Kim et al., 2015), and is substantially higher compared to the prevalence (30%) of workers not exposed to WBV (Bongers and Boshuizen, 1990). Therefore, given the large numbers of truck drivers in the working population, research to improve their occupational health and well-being is certainly merited.

Passive air suspension seats are the current industry standard practice to reduce WBV exposures in long-haul truck drivers. However, previous studies have shown that these passive air suspension seats have limited capability in WBV attenuation in on-road vehicles travelling at moderate to high speeds and amplify the vibration exposures in some instances, especially low-frequency vibrations (Thamsuwan et al., 2013; Kim et al., 2015). Recently, a new active vibration cancelling seat suspension has been developed. The seat uses a highly responsive electromagnetic linear actuator to continuously and nearly instantaneously controls the vertical up-and-down vibration-induced motions. Due to far greater fidelity in frequency response, this active suspension system is found to be far superior in reducing WBV compared to the conventional air suspension systems (Blood et al., 2011). A previous study on a standardized route showed that this new active suspension seat was much more effective in attenuating WBV exposures compared to a passive air suspension seat (Blood et al., 2011; Blood et al., 2015). This indicates that this new active suspension seat could be an effective engineering control to reduce WBV exposures among professional truck drivers.

Although there have been studies that have evaluated the associations between WBV exposure and adverse health outcomes, such as LBP, previous studies have typically been cross-sectional or retrospective in nature and WBV

exposures have been characterized from predominantly short duration measures. Therefore, the purpose of this randomized controlled trial (RCT) study was to determine whether seating interventions could improve truck drivers' musculoskeletal and other general health outcomes.

Methods

Subjects

Through Washington Trucking Associations, we identified five trucking companies in Washington State who provided access to truck drivers. From these five companies, we invited a total of 105 professional truck drivers to participate in the study (Fig. 1). While the companies employed additional drivers, some drivers were not available to participate in the study due to various

reasons including medical leave, shift timing, vacations, and being based in different geographic locations away from the main terminal. Among these 105 truck drivers, 96 drivers expressed their interest in the study participation and completed an eligibility questionnaire. Based on the analysis of the eligibility questionnaire, 53 truck drivers from four trucking companies were eligible for this RCT study. One company dropped out due to the sampling demands. Eligibility included that drivers were either regional or line-haul drivers, meaning they spent the majority of their day behind the wheel driving with minimum manual material handling; were experienced truck drivers with a minimum of 1 year employment at their current company; and self-reported that they had no plans to retire in the next 2 years. The 1-year tenure requirement was to minimize the chances of subject drop out due to turnover because turnover rates are much

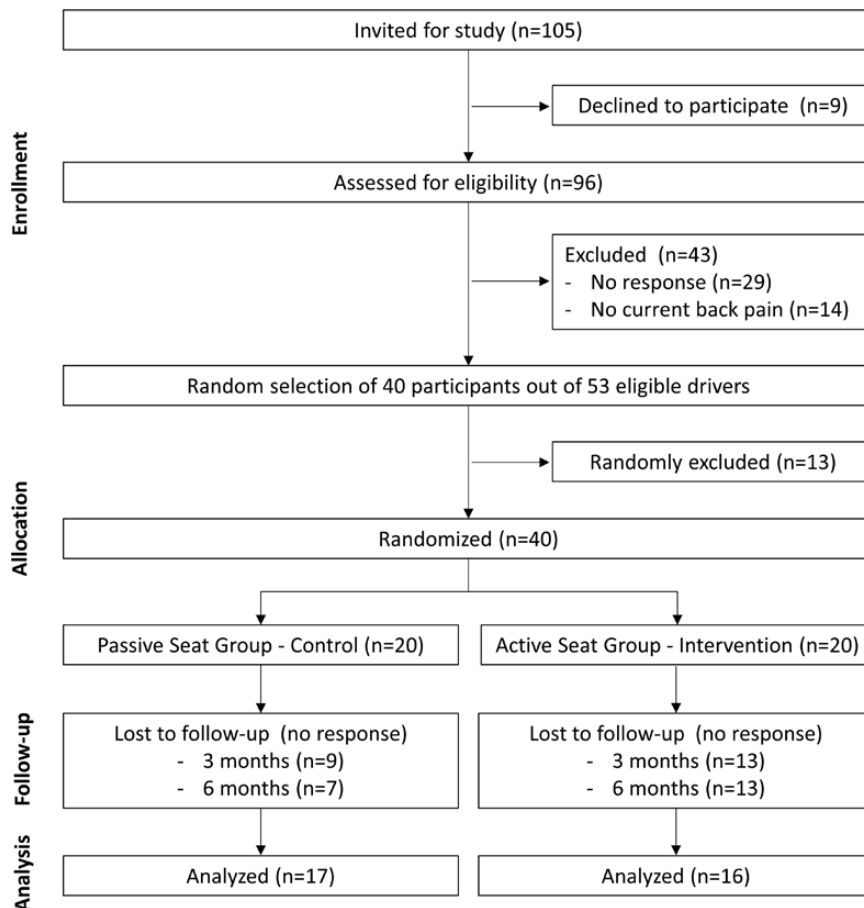


Figure 1. Study design showing the enrollment and allocation of participants to the control and intervention arms and participants lost to follow up. The analysis followed an intent-to-treat approach. If a subject dropped out of the study during the 1-year study period, we used the last observation carried forward method (Streiner and Geddes, 2001), meaning that the last available data prior to drop out will be included in the data analysis.

higher for new drivers in their first year of employment (Altas Ergonomics, 2009). Additional criteria included that all the drivers had their own dedicated trucks so that they used the intervention seats all the time during 1-year study period. Lastly, only truck drivers with current (past 7 days) LBP were included in this study as this study followed intent-to-treat approach. The experimental protocol was approved by the University's Human Subject Committee and all subjects gave their informed consent prior to their participation in the study.

Experimental design

From the pool of 53 eligible drivers, 40 drivers were randomly selected and assigned into two study arms with a computerized block randomization occurring within each company (Fig. 1). The non-selected 13 drivers were excluded from the study. A group of 20 drivers was assigned to the control group and received new industry-standard air-suspension seats (National Captain Seat; Commercial Vehicle Group; New Albany, OH or Sears Elite Seat; Sears Seating; Davenport, IA). The other group of 20 drivers was assigned to the intervention group and received new active-suspension seats (BoseRide; Bose Corporation; Framingham, MA). Having 20 subjects provided adequate power to detect meaningful differences in WBV exposure measures between two study arms (Part 1). However, since the focus of this paper was to measure health effects, and given the potential health effects of the seating interventions were not known, sample size was based on guidance for early stage clinical trials (Norfleet and Gad, 2009). In early stage clinical trials, often due to uncertainty, typically smaller number of subjects are evaluated (typically 10–30 subjects). So, with the known WBV exposures, the unknown health effects of the interventions and the financial limit of the

grant funding source, 40 subjects (20 subjects per arm) were evaluated in this study. The block randomization within a company minimized confounding that may be associated with the company (in particular differences in WBV exposures that may be associated with route differences across companies). After subject dropout and requiring repeated WBV measurements pre- and post-intervention, 17 control and 16 intervention drivers were included for subsequent analyses per intent-to-treat approaches (Fig. 1). The demographic information of the subjects is shown in Table 1, truck characteristics can be found in Table 1 of the first paper (Johnson et al., 2018).

Data collection and analysis

Musculoskeletal pain, general health outcomes, and psychosocial factors were measured at pre- (0 month) and post-intervention (3, 6, and 12 months) using standardized and validated questionnaires in order to determine whether anticipated changes in WBV through different seating interventions would have differential effects in health outcomes.

We utilized two pain scores, one for LBP to capture localized pain and then an overall body musculoskeletal pain scale to capture other parts of the body. Musculoskeletal pain outcomes on seven different body parts (low back, neck, shoulder, wrist/forearm, knee, ankle/feet, and leg/sciatica) were collected using a standardized 10-point pain scale adopted from the Standard Nordic Questionnaire (Kuorinka et al., 1987). The localized pain scale ranged from 0 to 10 with verbal anchors: 0 being 'no pain' and 10 being 'worse pain you can imagine'. Drivers were asked to rate the level of their pain when it was at the worst in the past week. The composite PAIN score was calculated as a sum of seven body pain ratings which could range from 0 (no

Table 1. Comparisons of participant demographics for the control and intervention arms.

	Control (n = 20)	Intervention (n = 20)	P-value
	Mean (SE)		
Weight (kg)	107.5 (8.1)	105.6 (4.4)	0.59
Height (cm)	178.3 (2.4)	182.9 (1.4)	0.24
BMI	33.7 (2.2)	31.5 (1.0)	0.29
Age (years)	49.1 (2.3)	48.9 (2.3)	0.72
	Likelihood Ratio Chi-Square ^a		
Tobacco Use		0.69	0.41
Alcohol Consumption		0.08	0.77
Physical Activity		4.78	0.31
History of Back Injuries		1.45	0.48

^aCalculated from multinomial logistic regression.

pain in any body area) to 70 (extremely severe pain in all body areas) to describe overall pain ratings of entire body (Amick et al., 2003). The PAIN scores were not calculated if any of the seven pain scores was missing.

Back functionality and disability were evaluated using the Oswestry Disability Index (ODI) questionnaire (Fairbank and Pynsent, 2000). The ODI questionnaire consists of 10 questions, each of which is scored on a scale of 0–5 with zero being the least amount of disability and 5 being most severe disability. If nine or more questions were completed, the ODI was calculated as follows:

$$ODI = \frac{\sum_{i=1}^{10} Q_i}{total\ possible\ score} \times 100 \quad \text{where}$$

Q_i : score of i^{th} question ODI

0 – 20	: minimal disability
21 – 40	: moderate disability
41 – 60	: severe disability
61 – 80	: Crippling back pain
81 – 100	: Patients are either bedbound or exaggerating their symptoms

If more than one question was missed, ODI was not calculated. Previous studies have shown that minimal clinically important changes range from 4 to 16 percentage points (Lauridsen et al., 2006).

The general physical and mental health were collected and evaluated relative to the US population using the 12-item Short Form (SF-12) survey (Ware, 1996). Through linear transformation of SF-12 raw scores, two composite summary measures including physical component summary and mental component summary were calculated according the methods proposed by Ware et al. (2002). The SF-12 health scores below or above the general US population's health score (mean: 50 and SD: 10) indicate lower or higher health status. Generally, the score difference greater than 20 indicates poor health and significant limitations.

The Work Limitation Questionnaire (WLQ) was used to measure the degree to which the truck drivers experienced limitation during their work due to their health problems and the productivity loss due to these work limitations during the past 2 weeks (Lerner et al., 2001). The WLQ scores consist of four scales: *Time Demand*, *Physical Demand*, *Mental Demand*, and *Output Demand*. *Time Demand* scale measures the difficulty in managing time and scheduling demands. *Physical Demand* scale measures a worker's ability to perform job tasks that involve physical strength, stamina, movement,

coordination and flexibility. *Mental Demand* scale evaluates psychological demand associated with cognitive tasks and interpersonal interactions at work. Lastly, *Output Demand* scale evaluates how much a worker's physical and emotional problems affect the productivity. Scale scores range from 0 (limited none of the time) to 100 (limited all of the time). Each scale ranges from 0 (no limitations) to 100 (most limitations). Based on the four WLQ scales, the productivity loss score was calculated to assess the percentage decrement in work output due to health problems (Lerner et al., 2003). A 10% increase in WLQ scores equals to 4–5% reduction in productivity (Lerner et al., 2003).

WBV

As outlined in the first paper (Johnson et al., 2018), WBV exposure data were collected at pre- and post-intervention according to international WBV standards (ISO 1997 and 2004). The ISO WBV exposure parameters included the daily root mean square weighted average vibration [A(8)], the daily Vibration Dose Value [VDV(8)], and the daily Static spinal compression dose [$S_{ed}(8)$]. The WBV exposures were collected temporally in parallel with the all the data reported here.

Statistical analysis

The analysis followed an intent-to-treat approach. If a subject dropped out of the study during 1-year study period, we used the last observation carried forward method (Streiner and Geddes, 2001), meaning that the last available data prior to drop out will be included in the data analysis. To check if the randomization minimized differences between the intervention and control group, we used multinomial logistic regression (JMP Pro 11; SAS Institute, Cary, SC) to examine differences between the study arms in important covariates such as age, body mass index (BMI), tobacco use, alcohol consumption, physical activity, history of back injuries (e.g. back strain/sprain and spinal fractures).

As the goodness of fit tests indicated that health outcome measures were normally distributed, a generalized linear mixed model was used to test the main hypothesis that there were differences in health outcomes between the two seat groups at 3 and 6 months poster intervention. The mix model set the seat (intervention or control) and time (3 and 6 months) as fixed effects while subject was a random effect nested within the truck company identifier. In addition, the mix model included a fixed effect term for the baseline (0 month) value for the dependent variables (health outcomes) being examined in the model. The model was run for each of our dependent variables. The health outcome-dependent variables

were LBP, the overall musculoskeletal pain of entire body (PAIN), back functionality/disability (ODI), SF-12, and WLQ. For post-hoc comparisons, *Dunnett's* tests were used to determine difference existed between the baseline and post intervention (3 and 6 months) measures. The effect sizes (ES) and 95% confidence intervals (CI) were calculated using *Hedges' g* because *Hedges's g* is less biased than *Cohen's d*, especially for a small sample size (*Hedges, 1981*). Similar to the interpretation Part 1 (*Johnson et al., 2018*), ES 0.20 or less were interpreted as small to negligible differences/changes, values near 0.50 moderate differences/changes and values greater than 0.80 large differences/changes. Clinical significance for LBP was set to 25% changes relative to baseline measures based on *Lauridsen et al. (2006)* Statistical significance was noted when *P*-values were less than 0.05.

Results

WBV

To briefly summarize the WBV exposure results of Part 1 (*Johnson et al., 2018*), there were no differences in the *x*- and *y*-axis WBV exposures between the two seats; however, there were parameter dependent *z*-axis exposure differences. The WBV exposure parameter dependence in the *z*-axis showed that the with both seats the greatest reductions were seen in the continuous weighted-average WBV exposures [A(8)]; to a lesser degree, with the time-weighted average impulsive measures [VDV(8)]; and to a very limited degree in the raw, impulsive exposure measures [$S_{ed}(8)$]. The A(8) values showed that the intervention group had almost a 50% reduction in the vertical (*z*) axis WBV exposures post-intervention compared to a 26% reduction in the passive suspension/control group. The *z*-axis VDV(8) and $S_{ed}(8)$ WBV exposure measures were not different between the two groups.

Health outcomes

As shown in *Table 1*, the multinomial logistic regression models found no statistically significant differences in the important covariates including age (*P* = 0.72), BMI (*P* = 0.28), tobacco use (*P* = 0.41), alcohol consumption (*P* = 0.77), physical activity (*P* = 0.31), and history of back injuries (*P* = 0.48). As none of these covariates differed between the study arms, we did not include any covariates in our evaluation of the main hypothesis.

As shown in *Fig. 3*, the baseline LBP of the intervention group was slightly higher compared to the control group [*P* = 0.06; Hedge's *g* ES (95% CI) = 0.67 (-1.37, 0.03)]. There were no differences in the baseline PAIN

[*P* = 0.79; ES (95% CI) = -0.33 (-1.18, 0.51)] and ODI [*P* = 0.43; ES (95% CI) = -0.24 (-0.97, 0.49)] between the study groups (*Fig. 2*). Despite no statistical significance post-intervention, the ES indicated that the intervention group that received the active-suspension seats experienced a greater reduction in the LBP and composite PAIN outcomes than the control group that received the new air-suspension seats (*Fig. 2*). Relative to the pre-intervention baseline LBP (3.3 ± 0.4), LBP scores in the intervention group were 35% [*P* = 0.13; ES (95% CI) = -0.45 (-1.19, 0.29)] lower at 3 months (2.2 ± 0.5), and 17% lower [*P* = 0.51; ES (95% CI) = -0.22 (-0.95, 0.52)] at 6-month post-intervention (2.8 ± 0.5). The post-intervention LBP in the control group showed that 3-month LBP (2.4 ± 0.6) was 16% lower [*P* = 0.22; ES (95% CI) = 0.02 (-0.79, 0.83)] than the pre-intervention measures (2.8 ± 0.4); however, 6 months post-intervention LBP (2.8 ± 0.7) was not different from the baseline measure [*P* = 0.79; ES (95% CI) = 0.07 (-0.81, 0.95)].

The composite PAIN scores slightly decreased over time for the intervention group whereas the PAIN scores increased for the control group; however, these changes and differences did not reach statistical significance. For the intervention group, the PAIN scores at 3-month (9.6 ± 2.4) and 6-month post-intervention (12.5 ± 2.6) were 32% [*P* = 0.35; ES (95% CI) = -0.05 (-0.89, 0.79)] and 11% lower [*P* = 0.85; ES (95% CI) = -0.41 (-1.28, 0.46)], respectively when compared to the baseline PAIN score (14.1 ± 1.8). For the control group, the PAIN scores at 3-month (14.1 ± 3.2) and 6-month (19.2 ± 3.7) post-intervention were 6% [*P* = 0.95; ES (95% CI) = 0.29 (-0.62, 1.19)] and 44% higher [*P* = 0.26; ES (95% CI) = 0.05 (-0.96, 1.07)], respectively than the baseline PAIN scores (13.4 ± 2.0).

Mean baseline ODI scores in the control (14.2 ± 1.8) and intervention group (15.0 ± 1.7) showed that truck drivers in this study were minimally impaired due to the LBP (*Fig. 2d*). After 3 months post-intervention, the mean ODI score in the intervention group (9.9 ± 2.3) decreased by 5 percentage points [*P* = 0.29; ES (95% CI) = -0.20 (-1.0, 0.60)], whereas the control group's ODI score (19.3 ± 3.0) increased by 5 percentage points [*P* = 0.04; ES (95% CI) = 0.44 (-0.44, 1.32)]. However, the changes relative to the baseline ODI negligible at 6-month post-intervention in both groups: changes were less than 2.5 percentage points (*P*'s > 0.70).

SF-12 health scores

The baseline SF-12 physical health scores (*Fig. 3*) in both the intervention (mean = $43.3 \pm SE = 1.3$) and control groups (43.7 ± 1.2) were not significantly different [*P* = 0.71; ES (95% CI) = 0.19 (-0.50, 0.87)]

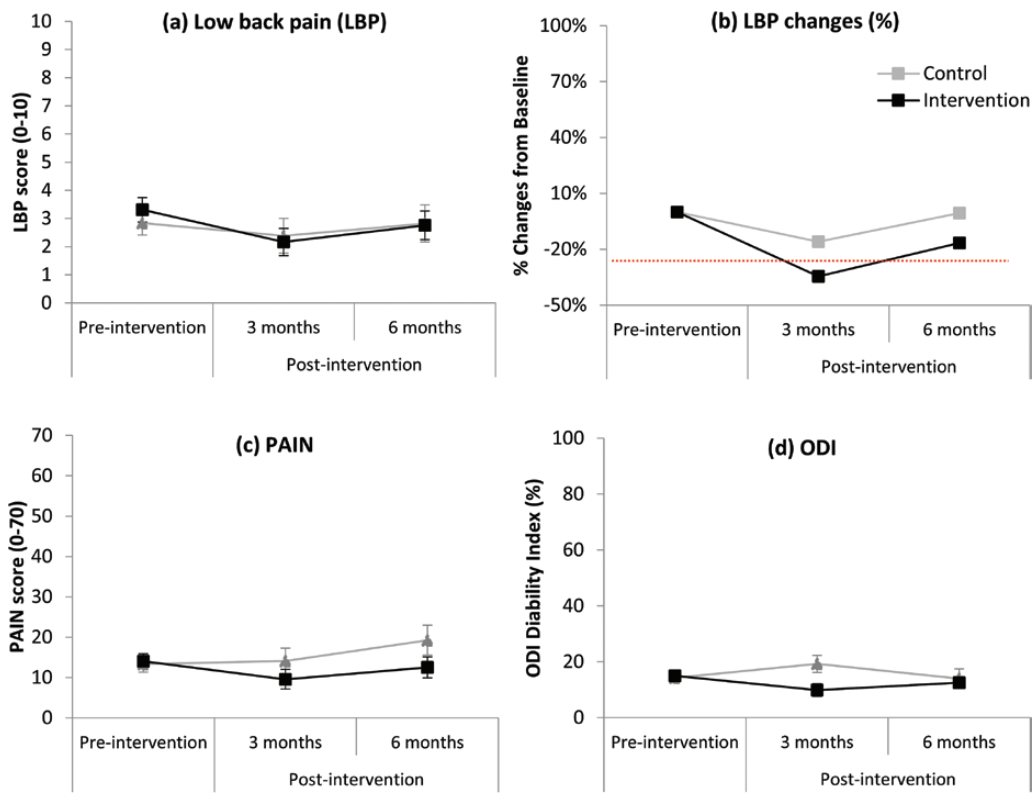


Figure 2. Mean (SE) comparisons of the LBP (a), % changes in LBP (b), composite PAIN (b), and ODI (c) score changes over time between the intervention and control group. The LBP scale ranges from 0 (no pain) to 10 (worse pain you can imagine). The PAIN scale ranged from 0 (no pain in any body area) to 70 (extremely severe pain in all body areas). The ODI ranged from 0 (no disability) to 100 (bedbound): 0–20: minimal disability; 20–40: moderate disability; 40–60: severe disability; 60–80: crippling back pain; 80–100: subjects are either bedbound or exaggerating their symptoms. The red dotted line indicates clinical significance: pain changes greater than 25% relative to baseline measures (Lauridsen et al., 2006).

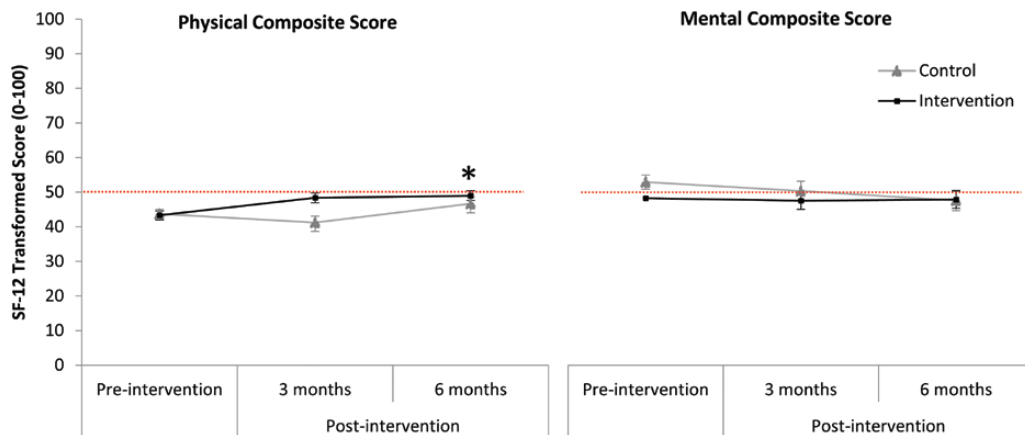


Figure 3. Mean (SE) comparisons of norm-based SF-12 physical and mental composite health score changes over time between the intervention and control groups. The red dotted lines indicate the general US population's health status. The asterisk indicates a statistically significant change in the intervention group relative to the baseline, determined by the Dunnett's test at $\alpha = 0.05$. Higher scores indicate better outcomes.

but significantly lower than the general US population's physical health score ($\mu = 49.6$ and $\sigma = 9.9$; P 's < 0.0001), indicating the truck driver's had a poorer health status relative to the general population. However, the baseline SF-12 mental health scores from both groups were not different from the general US population ($\mu = 49.4$ and $\sigma = 9.8$; P 's > 0.25). Relative to the pre-intervention SF-12 scores, the intervention group's physical health scores slightly increased (improved) at 3-month [48.4 ± 1.2 ; $P = 0.06$; ES (95% CI) = 0.60 (-0.14, 1.33)] and 6-month [49.0 ± 2.0 ; $P = 0.04$; ES (95% CI) = 0.02 (-0.12, 1.35)] post-intervention. Relative to the intervention group, the control group had smaller improvements in physical health scores at 3-month [41.2 ± 1.8 ; $P = 0.11$; ES (95% CI) = -0.020 (-1.0, 0.6)] and 6-month [46.7 ± 2.0 ; $P = 0.16$; ES (95% CI) = 0.63 (-0.27, 1.53)] post-intervention.

WLQ

WLQ scores showed that the intervention group in general experienced reduced work limitation (improvement) in all four scales over time whereas the control group had inconsistent changes in work limitation scores (Fig. 4). Relative to baseline (19.1 ± 2.8), *Time Demand* (mean \pm SE) in the intervention group was significantly lower at 3-month [5.2 ± 3.2 ; $P = 0.01$; ES (95% CI) = -0.98 (-1.73, -0.235)] and 6-month post-intervention [8.3 ± 3.0 ; $P = 0.04$; ES (95% CI) = -0.73 (-1.45, -0.01)]; in contrast, *Time Demand* in the control group did not change (P 's > 0.46). Similarly, *Physical Demand* in the intervention group decreased at 3 months [15.8 ± 5.3 ; $P = 0.02$; ES (95% CI) = -0.86 (-1.61, -0.11)] and 6 months [22.2 ± 5.2 ; $P = 0.14$; ES (95% CI) = -0.39 (-1.11, 0.33)] from the baseline (34.2 ± 4.8) whereas relative to the baseline measures in the control

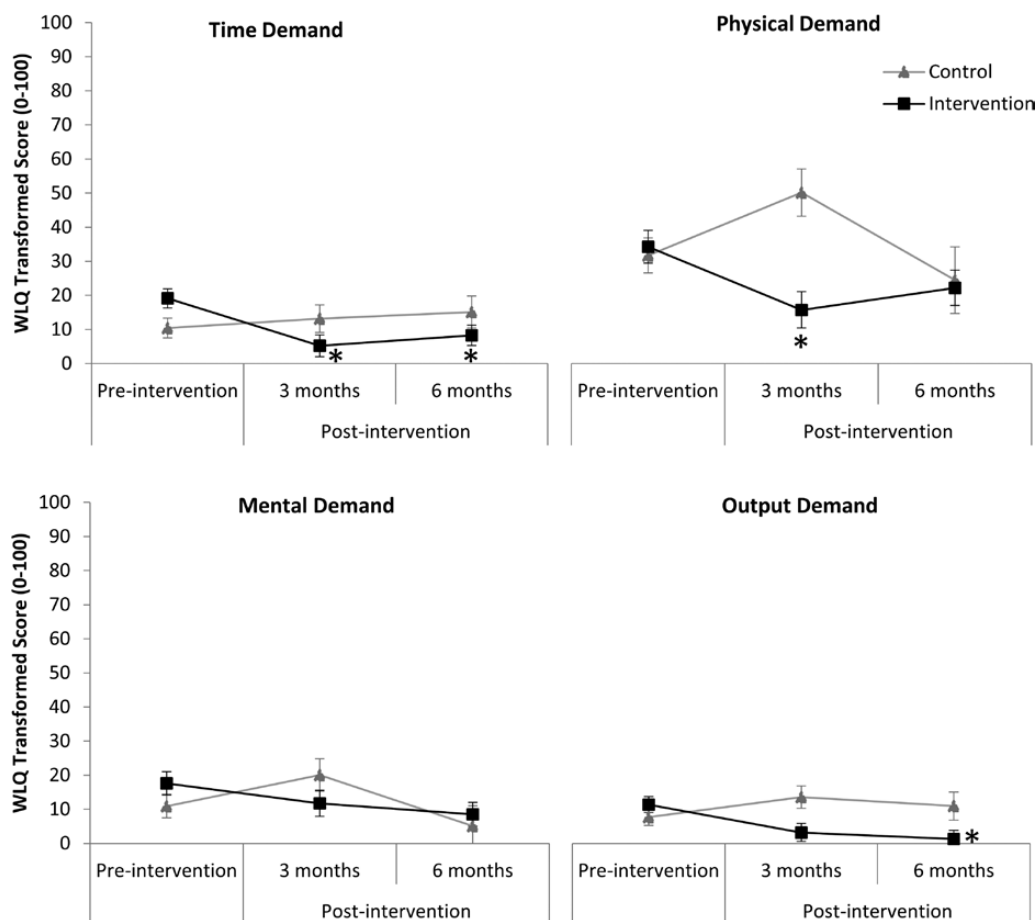


Figure 4. Mean (SE) comparisons of Work Limitation Questionnaire (WLQ) changes over time between the intervention and control group. WLQ scores range from 0 (no limitations) to 100 (most limitations). Asterisks indicate statistically significant changes in the intervention group relative to the baseline, determined by *Dunnett's* tests at $\alpha = 0.05$. Lower scores indicate better outcomes.

group (31.7 ± 5.1), there was no changes in *Physical Demand* at 3 months [50.2 ± 6.9 ; $P = 0.09$; ES (95% CI) = 0.13 (-0.66, 0.92)] and some reduction but not statistically significant changes at 6 months [24.5 ± 9.8 ; $P = 0.84$; ES (95% CI) = -0.41 (-1.38, 0.55)]. *Mental Demand* did not change in both intervention and control groups. *Output demand* in the intervention group was lower at 3-month [3.2 ± 2.6 ; $P = 0.06$; ES (95% CI) = -0.61 (-1.36, 0.13)] and 6-month post-intervention [1.3 ± 2.5 ; $P = 0.02$; ES (95% CI) = -0.75 (-1.49, -0.01)] than the baseline score (11.4 ± 2.3); however, the control group showed a slight increase at 3 months [13.6 ± 3.3 ; $P = 0.11$; ES (95% CI) = 0.38 (-0.42, 1.17)] and no changes at 6-month post-intervention [10.9 ± 4.2 ; $P = 0.44$; ES (95% CI) = 0.09 (0.87, 1.04)] when compared to the baseline (7.7 ± 2.4).

Discussion

This RCT study evaluated a new engineering control (active suspension seat) designed to reduce truck drivers' exposure to WBV relative to the industry-standard passive (air) suspension seat in order to determine whether reduced WBV exposures improved associated health outcomes. The results from Part 1 (Johnson et al., 2018), indicated that the intervention group with the active suspension seats had no differences in x- and y-axis exposures, but experienced a greater reduction in z-axis A(8) WBV exposures and no differences in impulsive [VDV(8) and Sed(8)] WBV exposures. In parallel with the reduction in the z-axis A(8) exposures in the intervention group, there were improvements in many of the associated health outcomes, as compared to the control group (Figs 2–4).

The self-reported musculoskeletal health outcomes showed that intervention group experienced greater reductions in the LBP and composite PAIN (sum of pain scores from seven body parts) outcomes than the control group (Fig. 2); however, these changes did not reach statistical significance. The lack of statistical significance is likely due to sample size and lack of statistical power; however, the 35% reduction of LBP in the intervention group may be meaningful as a pain decrease of at least 25% from baseline measures is considered as clinically important (Lauridsen et al., 2006). These findings were also supported by the relatively greater ES in the intervention group (ES: 0.22–0.45) as compared to the control group (ES: 0.02–0.07). In addition, the intervention group's 95% ES CI was asymmetrical and mostly below zero (indicating a reduction in LBP and PAIN) whereas the control group's 95% CI was relatively symmetric about zero (indicating little to no reduction).

These changes in the pain outcomes mirrored only the the z-axis A(8) WBV exposure changes between pre- and post-intervention in Part 1 of this study (Johnson et al., 2018). That is, the greater A(8) WBV exposure reduction resulted in the greater pain reduction in the intervention group while the control group experienced relatively smaller reduction in the A(8) WBV exposures and associated pain outcomes. These results indicated that reducing truck drivers' A(8) exposures through seating interventions may reduce musculoskeletal pain; however, a larger sample sized trial is needed.

The ODI also showed that the intervention group experienced decreased low back disability whereas the control group showed a slight increase in low back disability. Although some studies have shown that minimal clinically important changes of ODI ranges from 4 to 16 percentage points (Lauridsen et al., 2006), these reductions in the ODI in the intervention group were no more than 5 percentage points which is less than 10%, the minimal detectable changes of the ODI (Fairbank and Pynsent, 2000). The small ES also showed that the changes in the disability may not be meaningful. This lack of change may be in part because this index was originally used for pre- and post-surgical assessment (patients with more severe low back disability) so the scale may be less sensitive to detecting changes in low back functionality in working truck drivers whose low back disability is much less compared to patients with low back surgery (Davies and Nitz, 2009). The Roland Morris Disability index may be a more suitable scale for future studies measuring low back disability in truck drivers.

The baseline SF-12 scores showed that professional truck drivers in this study had lower physical health but similar mental health as compared to the general US population. This correlates with a high prevalence (50–80%) of various musculoskeletal disorders among professional drivers (Schwarze et al., 1998; Bovenzi et al., 2002; Bovenzi et al., 2006; Bovenzi et al., 2009; Kim et al. 2016). The SF-12 physical health scores showed that the intervention group experienced greater improvement in physical health scores as compared to the control group, while both groups did not experience any changes in mental health. Such changes in SF-12 physical health scores were similar to those found in LBP and PAIN outcomes as discussed above. These results showed that substantially reducing truck drivers' exposure to z-axis average continuous vibration (A(8) exposures) with high performing seats may have potential to improve general physical health of truck drivers, which is also supported by moderate ES (around 0.5).

WLQ scores showed that the intervention group generally experienced reduced (improved) work limitation in all four scales over time whereas the control group showed inconsistent changes in work limitation scores (Fig. 4). The pre-intervention WLQ scores indicated that truck drivers had higher Time Demand and Physical Demand when compared to the healthy population without occupational driving tasks found by Lerner et al. (2001). Previous studies have identified this high time demand as a risk factor associated with drivers' fatigue, longer recovery time, accidents, and adverse psychological health problems (de Croon et al., 2000; McCartt et al., 2000; de Croon et al., 2003; Shattell et al., 2010). Furthermore, although the drivers in this study had no to minimal manual material handling, they still perceived that their long-hour driving was physically demanding. The high physical demand is a known risk factor for musculoskeletal disorders and a strong predictor for sickness absence (de Croon et al., 2003). These high job demands may in part explain the high prevalence of musculoskeletal disorders among professional truck drivers (Schwarze et al., 1998; Bovenzi et al., 2002; Bovenzi et al., 2006; Bovenzi et al., 2009; Kim et al., 2016).

The pre-intervention WLQ Productivity Loss Scores indicated that the intervention and control group experienced approximately 4.9% and 3.4% productivity loss, respectively, in the past 2 weeks due to their health problems. Given that truck drivers usually drive up to 11 h/day and 5 days/week, these productivity losses mean that between 3.8 and 5.4 h of driving time could have been lost in the last 2 weeks due to the health problem. The productivity losses of the truck drivers in this study were slightly higher than the general healthy population's WLQ productivity loss (2.2%) (Lerner et al., 2002). After the intervention, the WLQ Productivity Loss of the intervention group improved and went from 5.0% down to 2.1%, whereas the control group did not experience any reduction on the productivity loss.

The reduced productivity loss of the intervention group who experienced significant reduction of WBV exposures is in line with the decrease in musculoskeletal pain (LBP and PAIN), low back disability (ODI), and physical health (SF-12). This result indicates that reducing exposure to WBV may also improve the productivity through improving driver's physical health outcomes. Given that 70 h per week is the legally-allowed driving time in the USA, the 2.9% reduction in the productivity loss would result in 4.1 h of productivity gains over a 2-week period. Based on median truck driver annual salary (\$73,000 according to American Trucking Association), this reduction would equate to a saving of \$2,117 per year.

Strengths and limitations

Strength of our study is the study design, a RCT. To date, there have been no systematic, prospective studies evaluating new seat suspension technologies/interventions as an engineering control to reduce WBV exposures and/or characterizing the subsequent health effects (e.g. changes in LBP and low back function). In fact, a National Research Council report on work-related MSDs highlighted the need for rigorous studies including randomized controlled trials and other scientifically sound approaches on workplace interventions as a way to build evidence-based approaches to the prevention of work-related musculoskeletal disorders (National Research Council, Institute of Medicine, 2001). Therefore, we believe that this study demonstrates that high quality seating interventions, which substantially reduce truck drivers' exposure to continuous, cyclical average weighted vibration exposures, has the potential to improve associated health outcomes.

However, this study does have some limitations. First, this RCT study had a small sample size ($n = 20$ per study arm). Our power calculation based on our previous studies (Johnson and Blood, 2011) showed that this sample size would provide at least 80% of statistical power to detect the differences in WBV exposures over time as well as between the intervention and control group. However, this sample size was not large enough to detect the changes in health outcomes. This small sample size may have resulted in lack of statistical differences in LBP despite the clinically meaningful difference observed. This is likely true for the other parameters measured as well. Second, as a longitudinal study, this study had significant drop out; this is in part because trucking industries have been experiencing very high turnover rate over the past few decades (Costello and Suarez, 2015). The drop-out rates were 30% by 3 months post-intervention and 40% by 6 months post-intervention. Because more than 80% of study participants had dropped or we could not get measures at the 12-month post-intervention period, we decided to exclude the 12-month post-intervention data from the statistical data analysis. Such high drop-out rates likely further affected the statistical power of this study; therefore, a careful interpretation of the study results may be merited.

Conclusions

This RCT study was conducted to determine whether truck driver seats, designed to reduce WBV exposures (an engineering intervention), improved truck driver's LBP, and other health outcomes. The study results demonstrate that the intervention (active suspension) truck seat, substantially reduced average weighted vibration [A(8)] exposures and appeared to be more effective in

reducing LBP and improving other physical health outcomes compared to the control (passive air-suspension) seat. Although many of these changes in the health outcomes were not statistically significant (in part due to the small sample size), LBP changes were clinically meaningful (Lauridsen et al., 2006) and improvements in other health outcomes were consistent with the LBP results in the truck drivers receiving the intervention seat. Therefore, the study findings indicate that reducing truck drivers' exposure to WBV can improve their LBP and other physical health outcomes and that seating interventions, which reduce WBV exposures, can be effective engineering intervention to improve truck driver's physical health and low back functionality.

Acknowledgements

We would like to thank Lovenoor Aulck and Margaret Hughes for their assistance in data collection and preparation for analysis. We would also like to thank the Washington Trucking Association for all the support for recruiting the trucking companies and thank all the trucking companies and truck drivers who participated in this study.

Funding

This research was supported by a research grant from Safety & Health Investment Projects (SHIP) Grant Program in the State of Washington.

Conflict of Interest

The authors declare no conflict of interest.

References

- Ammendolia C, Cassidy D, Steensta I et al. (2009) Designing a workplace return-to-work program for occupational low back pain: an intervention mapping approach. *BMC Musculoskelet Disord*; 10: 65.
- Amick BC III, Habeck RV, Ossmann J et al. (2004) Predictors of successful work role functioning after carpal tunnel release surgery. *J Occup Environ Med*; 46: 490–500.
- Anderson GBJ. (1998) Epidemiology of low back pain. *Acta Orthopaedica Scandinavica*. 69: 28–31.
- Aulck LS. (2012) *Ex vivo biomechanical testing to examine the etiology of low back pain as a result of whole body vibration*. Master's Thesis. Seattle, WA: University of Washington.
- Bernard BP. (1997) *Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*. DHHS (NIOSH) Publication No. 97–141. Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.
- Blood R, Dennerlein J, Lewis L, Rynell P, Johnson P. (2011) Evaluating whole-body vibration reduction by comparison of active and passive suspension seats in semi-trucks. *Proceedings of the Human Factors and Ergonomics Society's 55th Annual Meeting*, pp 1750–4.
- Blood RP, Yost MG, Camp JE et al. (2015) Whole-body vibration exposure intervention among professional bus and truck drivers: a laboratory evaluation of seat-suspension designs. *J Occup Environ Hyg*; 12: 351–62.
- Bongers PM, Boshuizen HC. (1990) *Back disorders and whole-body vibration at work*. Amsterdam: Academisch Proefschrift., Universiteit van Amssterdam.
- Bovenzi M. (1996) Low back pain disorders and exposure to whole-body vibration in the workplace. *Semin Perinatol*; 20: 38–53.
- Bovenzi M. (2009) Metrics of whole-body vibration and exposure-response relationship for low back pain in professional drivers: a prospective cohort study. *Int Arch Occup Environ Health*; 82: 893–917.
- Bovenzi M, Hulshof CT. (1999) An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986-1997). *Int Arch Occup Environ Health*; 72: 351–65.
- Bovenzi M, Pinto I, Stacchini N. (2002) Low back pain in port machinery operators. *J Sound Vib*; 253: 3–20.
- Bovenzi M, Rui F, Negro C et al. (2006) An epidemiological study of low back pain in professional drivers. *J Sound Vib*; 298: 514–39.
- Costello B, Suarez R. (2015) Truck driver shortage analysis 2015. Available from <http://www.trucking.org/ATA%20Docs/News%20and%20Information/Reports%20Trends%20and%20Statistics/10%206%2015%20ATAs%20Driver%20Shortage%20Report%202015.pdf> (accessed 1 August 2016).
- de Croon EM, van der Beek AJ, Blonk RWB et al. (2000) Job stress and psychosomatic health complaints among Dutch truck drivers: a re-evaluation of Karasek's interactive job demand-control model. *Accid Anal Prev*; 32: 493–504.
- de Croon EM, Sluiter JK, Frings-Dresen MH. (2003) Need for recovery after work predicts sickness absence: a 2-year prospective cohort study in truck drivers. *J Psychosom Res*; 55: 331–9.
- Davies CC, Nitz AJ. (2009) Psychometric properties of the Roland-Morris disability questionnaire compared to the Oswestry Disability Index: a systematic review. *Phys Ther Reviews*; 14: 339–408.
- Fairbank JC, Pynsent PB. (2000) The Oswestry Disability Index. *Spine (Phila Pa 1976)*; 25: 2940–52; discussion 2952.
- Fritz M. (1997) Estimation of spine forces under whole-body vibration by means of a biomechanical model and transfer functions. *Aviat Space Environ Med*; 68: 512–9.
- Fritz M. (2000) Description of the relation between the forces acting in the lumbar spine and whole-body vibrations by means of transfer functions. *Clin Biomech (Bristol, Avon)*; 15: 234–40.
- Griffin MJ. (1990) *Handbook of human vibration*. London: Academic Press Ltd. ISBN: 0123030404.
- Hedges LV (1981). Distribution theory for Glass' estimator of effect size and related estimators. *J Educ Stat*; 6: 107–28.
- International Organization for Standardization. (1997) ISO 2631-1: mechanical vibration and shock – Evaluation of

- human exposure to whole-body vibration – Part I: general requirements.
- International Organization for Standardization. (2004) ISO 2631–5: mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part V: method for evaluation of vibration containing multiple shocks.
- Johnson PW, Blood PR. (2011) *Evaluating whole-body vibration exposure engineering control options in a population of semi-truck drivers: comparison of an active and passive suspension seat*. 38th Annual Conference of the Association of Canadian Ergonomists, Ontario, Canada.
- Johnson PW, Zigman M, Ibbotson J *et al.* (2018) A randomized controlled trial of a truck seat intervention: part 1 – assessment of whole body vibration exposures. *Ann Work Expo Health*; XX: XXX–XXX.
- Kim JH, Zigman M, Aulck LS *et al.* (2015) *Reduced exposure to whole body vibration improves low back pain among professional truck drivers: a randomized controlled trial study*. 19th triennial congress of International Ergonomics Association in Melbourne Australia.
- Kim JH, Zigman M, Aulck LS *et al.* (2016) Whole body vibration exposures and health status among professional truck drivers: a cross-sectional analysis. *Ann Occup Hyg*; 60: 936–48.
- Kuorinka I, Jonsson B, Kilbom A *et al.* (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon*; 18: 233–7.
- Lauridsen HH, Hartvigsen J, Manniche C *et al.* (2006) Responsiveness and minimal clinically important difference for pain and disability instruments in low back pain patients. *BMC Musculoskelet Disord*; 7: 82.
- Leigh JP. (2011) Economic burden of occupational injury and illness in the United States. *Milbank Q*; 89: 728–72.
- Lerner D, Amick BC III, Lee JC *et al.* (2003) Relationship of employee-reported work limitations to work productivity. *Med Care*; 41: 649–59.
- Lerner D, Amick BC III, Rogers WH *et al.* (2001) The work limitations questionnaire. *Med Care*; 39: 72–85.
- Marcum J, Adams D. (2017) Work-related musculoskeletal disorder surveillance using the Washington state workers' compensation system: recent declines and patterns by industry, 1999–2013. *Am J Ind Med*; 60: 457–71.
- Marras WS. (2000) Occupational low back disorder causation and control. *Ergonomics*; 43: 880–902.
- McCart AT, Rohrbaugh JW, Hammer MC *et al.* (2000) Factors associated with falling asleep at the wheel among long-distance truck drivers. *Accid Anal Prev*; 32: 493–504.
- National Research Council/Institute of Medicine. (2001) *Panel on Musculoskeletal Disorders and the Workplace. Commission on Behavioral and Social Sciences and Education. Musculoskeletal disorders and the workplace: low back and upper extremities*. Washington, DC: National Academy Press.
- Norfleet E, Gad SC, “Phase I Clinical Trials”, in *Shayne Cox Gad, Clinical Trials Handbook*, New Jersey: Wiley. ISBN 978-0-470-46635-3, 2009, pp. 245–254
- Pope MH. (1991) *Occupational low back pain: assessment, treatment, and prevention*. St. Louis: Mosby Year Book. ISBN: 0801662524.
- Punnett L, Prüss-Ustün A, Nelson DI *et al.* (2005) Estimating the global burden of low back pain attributable to combined occupational exposures. *Am J Ind Med*; 48: 459–69.
- Rauser E, Foley M, Bonauto D *et al.* (2008) *Preventing injuries in the trucking industry*. Washington State Department of Labor & Industries, Technical Report No. 90-17-2008. Available from <http://www.lni.wa.gov/Safety/Research/Files/Trucking/PreventingTruckingInjuries.pdf> (accessed 1 August 2016).
- Rauser E, Smith C, Williams J. (2014) *Trucking Industry: Examining Injuries for Prevention, 2006–2012*. SHARP Program, Washington State Department of Labor & Industries, Technical Report No. 90-148-2014. Available from <http://www.lni.wa.gov/Safety/Research/Files/Trucking/901482014.pdf> (accessed 1 August 2016).
- Schwarze S, Notbohm G, Dupuis H *et al.* (1998) Dose-response relationships between whole-body vibration and lumbar disk disease - A field study on 388 drivers of different vehicles. *J Sound Vib*; 215: 613–28.
- Shattell M, Apostolopoulos Y, Sönmez S *et al.* (2010) Occupational stressors and the mental health of truckers. *Issues Ment Health Nurs*; 31: 561–8.
- Smith CK, Williams J. (2014) Work related injuries in Washington State's Trucking Industry, by industry sector and occupation. *Accid Anal Prev*; 65: 63–71.
- Streiner D, Geddes J. (2001) Intention to treat analysis in clinical trials when there are missing data. *Evid Based Ment Health*; 4: 70–1.
- Teschke K, Nicol A, Davies H *et al.* (1999). *Whole body vibrations and back disorders among motor vehicle drivers and heavy equipment operators: a review of the scientific evidence*. Vancouver, BC: University of British Columbia. Center for Health and Environment Research.
- Thalheimer E. (1996) Practical approach to measurement and evaluation of exposure to whole-body vibration in the workplace. *Semin Perinatol*; 20: 77–89.
- Thamsuwan O, Blood RP, Ching RP *et al.* (2013) Whole body vibration exposures in bus drivers: a comparison between a high-floor coach and a low-floor city bus. *Int J Ind Ergon*; 43: 9–17.
- Troup JDG. (1988). Clinical effects of shock and vibration on the spine. *Clin Biomech*; 3: 227–31.
- Ware JE Jr. (1996) Patient-based assessment: tools for monitoring and improving healthcare outcomes. *Behav Healthc Tomorrow*; 5: 88, 87.
- Ware JE, Kosinski M, Turner-Bowker DM *et al.* (2002) *User's Manual for the SF-12v2® Health Survey With a Supplement Documenting SF-12® Health Survey*. Lincoln, RI: QualityMetric Incorporated.
- Webster BS, Snook SH. (1994) The cost of 1989 workers' compensation low back pain claims. *Spine (Phila Pa 1976)*; 19: 1111–5; discussion 1116.
- Wilder DG, Aleksiev AR, Magnusson ML *et al.* (1996) Muscular response to sudden load. A tool to evaluate fatigue and rehabilitation. *Spine (Phila Pa 1976)*; 21: 2628–39.