A. COVER PAGE

Project Title: Effects of Multi-axial Whole Body Vibrations on Postural Stability	
Grant Number: 5R21OH011538-02	**Project/Grant Period:** 09/15/2019 - 09/14/2021
Reporting Period: 09/15/2020 - 09/14/2021	**Requested Budget Period:** 09/15/2020 - 09/14/2021
Report Term Frequency: Final	**Date Submitted:** 11/29/2023
Program Director/Principal Investigator Information: JEONGHO KIM , PHD **Phone Number:** 541-737-2166 **Email:** jay.kim@oregonstate.edu	**Recipient Organization:** OREGON STATE UNIVERSITY OREGON STATE UNIVERSITY A312 Kerr Administration Building CORVALLIS, OR 973318555 **DUNS:** 053599908 **UEI:** MZ4DYXE1SL98 **EIN:** 1611730890A1 **RECIPIENT ID:**
Change of Contact PD/PI: NA	
Administrative Official: CINDY L TAITWITHROW 312 Kerr Administration Building Corvallis, OR 973312140 **Phone number:** 541-737-4933 **Email:** cindy.tait-withrow@oregonstate.edu	**Signing Official:** CINDY L TAITWITHROW 312 Kerr Administration Building Corvallis, OR 973312140 **Phone number:** 541-737-4933 **Email:** cindy.tait-withrow@oregonstate.edu
Human Subjects: NA	**Vertebrate Animals:** NA
hESC: No	**Inventions/Patents:** No

B. ACCOMPLISHMENTS

B.1 WHAT ARE THE MAJOR GOALS OF THE PROJECT?

Professional vehicle operators suffer from the highest rates of both fatal and non-fatal occupational injuries.1,2 Fall-related injuries in particular accounted for 17% of all fatal and 27% of all non-fatal injuries in 2014.1,2 These fall-related injuries occur at a much higher rate (up to 8 times) during egress vs. ingress of vehicles.3-5 A likely cause for the disproportionally high fall-related injury rates during egress is a loss of postural stability3,6. Prolonged exposure to Whole Body Vibration (WBV) negatively affects postural stability5-8, by increasing neuromuscular reaction times9-13 and adversely affecting the visual, vestibular, and somatosensory systems involved in maintaining balance6,14-23, thereby increasing the risk of falling.
In off-road vehicles (e.g., agricultural and mining vehicles), WBV exposures are multi-axial, meaning that the predominant WBV exposure is not necessarily limited to the vertical (z-axis) but can often include significant fore-aft (x-axis) and/or lateral (y-axis) WBV exposures 24-26. Such multi-axial components of WBV exposures often have more detrimental effects on human responses24,26,28. Furthermore, the multi-axial components of WBV can increase head acceleration26 more so than vertical vibrations, and these components may further impair vestibular system responses and further reduce postural stability. Thus, off-road vehicle operators are at even greater fall-related injury risks compared to on-road drivers whose WBV exposures are predominantly on the vertical axis. However, the nature of the additional impact of multi-axial WBV on fall-related risk (e.g., postural stability) is poorly understood.28 Moreover, we do not have effective mechanisms to mitigate multi-axial WBV exposures, because current engineering approaches to reduce these exposures rely on passive vertical (z-axis) suspension systems.26 Therefore, to serve this critical need for applied research, our objectives in this application are to quantify the impact of multi-axial WBV exposure on postural stability, and to understand how this impact may be mitigated. This work supports our longer-term goal of reducing the prevalence of falling and related injuries among professional drivers.
Our central hypothesis is that exposure to multi-axial WBV increases the risk of falling more so than single-axial vertical WBV by impairing postural stability. We also hypothesize that this risk can be mitigated more effectively by a multi-axial active suspension seat than the current industry standard of single-axial (vertical) passive suspension seats. These hypotheses are supported by our preliminary work showing that exposure to lateral-dominant WBV significantly increases head acceleration,26 which is known to affect postural stability24,28. In addition, the increased head acceleration during multi-axial WBV exposure was more effectively reduced by using a new multi-axial active suspension compared to industry-standard seat suspensions.26
Our rationale for the current project is that if we can use an effective engineering control to reduce multi-axial WBV to levels previously unobtainable, we can alleviate the associated loss in postural stability and therefore lower risks for fall-related injuries among off-road vehicle operators. To achieve our research objectives, we propose a repeated-measures laboratory study using 25 subjects, in which we will replicate actual field-measured multi-axial vibration profiles and measure important aspects of postural stability in the following specific aims:

Specific Aim 1: Determine the relative impact of single- and multi-axial WBV exposure on postural stability . Our working hypothesis is that exposure to WBV with significant multi-axial components will, as compared to vertical-dominant WBV: (i) reduce functional limits of stability, (ii) increase sway during quiet standing (reduced standing balance), and (iii) prolong the duration of the preparatory imbalance phase and increase center-of-pressure displacement during the preparatory imbalance phase preceding functional tasks such as gait initiation and stair descent (impaired anticipatory postural adjustments).

Specific Aim 2: Determine the efficacy of single-axial passive and multi-axial active suspension seats in alleviating the adverse effects of multi-axial WBV on postural stability. Our working hypothesis here is that the use of a multi-axial suspension seat will alleviate the effects of multiaxial WBV on postural stability measures better than a single-axial passive suspension seat. Outcome measures will be the same as used in Specific Aim1.

The primary expected outcome of this proposed study is a clear delineation of the relative impact of single- and multi-axial WBV exposures on postural stability among off-road vehicle operators. This outcome will provide the neurophysiological underpinnings relating the type and extent of WBV with the risk of fall-related injuries. If, as expected, an innovative engineering control evaluated in this study reduces exposure to multi-axial WBV and its adverse effects on postural balance more effectively than industry-standard approaches, our results have great potential to change industry practice and reduce fall-related injury risks. Equally important, the results are expected to have substantial translational impact, because understanding the extents to which the different aspects of postural stability (i.e., the three measures listed above) are

affected by multi-axial WBV will help understand the relative contribution of the different underlying postural control systems. This, in turn, will provide a basis for developing new engineering controls to reduce multi-axial WBV and help in better targeting such future interventions to improve occupational health outcomes among vehicle operators.

B.1.a Have the major goals changed since the initial competing award or previous report?

No

B.2 WHAT WAS ACCOMPLISHED UNDER THESE GOALS?

File Uploaded : B2_Final RPPR_R21_WBV_balance.pdf

B.3 COMPETITIVE REVISIONS/ADMINISTRATIVE SUPPLEMENTS

For this reporting period, is there one or more Revision/Supplement associated with this award for which reporting is required?

No

B.4 WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?

File Uploaded : B3_Final RPPR_R21_WBV_balance.pdf

B.5 HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?

NOTHING TO REPORT

B.6 WHAT DO YOU PLAN TO DO DURING THE NEXT REPORTING PERIOD TO ACCOMPLISH THE GOALS?

Not Applicable

B.2 (B2_Final RPPR_R21_WBV_balance.pdf)

B.2 Accomplishments under these goals

1) Major Activities accomplished

We successfully accomplished the specific aims of the project. This project quantified the relative impacts of single- and multi-axial whole body vibration (WBV) exposures on postural control (specific aim 1) and evaluated the effectiveness of an intervention (i.e., multi-axial active suspension seat) to mitigate WBV-related postural control impairment (specific aim 2). The study results have been actively dissimilated through conference presentations and peer-review journal article (to be submitted in a few weeks). Detailed major activities are following:

- We completed a repeated-measures laboratory study with 25 subjects who participated in four exposure conditions that were administered over 4 different days with at least 24-hour gap between the conditions.
- To expose participants to WBV, we replicated actual field-measured vibration profiles: vertical-dominant (collected from semi-truck operation on paved roads) and multi-axial WBV (collected from mining heavy equipment vehicle operation on off road).
- Before and after WBV exposures, we collected a comprehensive set of postural control measures: sit-to-stand transitions, static stance on a foam surface, and stair descent.
- We processed all the raw data, computed a variety of metrics quantifying postural stability and fall risk, performed statistical analysis, and summarized all the results.
- The study results were published as conference proceedings/abstracts and presented at two international conferences: Institute of Industrial and Systems Engineers (IISE) Annual Conference Expo 2023 in New Orleans, LA and 67th International Annual Meeting of Human Factors and Ergonomics Society (HFES 2023) in Washington D.C.
- A manuscript is in preparation for submission to an archival journal (currently under internal review by the PIs).

2) Significant Results

- Prolonged sitting without WBV (i.e., control condition) by itself impaired postural control.
- Both vertical-dominant and multi-axial WBV negatively affected postural control.
- While limited differences on postural control measures were observed between the two types of WBV exposures, off-road vehicles' multi-axial WBV had greater impact on some of the postural control measures compared to on-road vehicles' vertical-dominant WBV.
- The multi-axial active suspension seat did not exhibit superior performance in mitigating the effects of multi-axial WBV on postural control when compared to the vertical-axial passive suspension seat.
- The study suggests that taking even a brief break of 30 minutes could offer drivers the advantage of recovering from potential postural control impairments associated with both WBV and prolonged sitting.

3) Key outcomes

- This was the first study that successfully evaluated the effects of different types of WBV on postural control using a comprehensive set of measures in static and dynamic postural control tasks: sit-to-stand transitions, static stance on a foam surface, and stair descent.
- Results were disseminated as two international conference presentations with published proceedings.
- A manuscript has been prepared for a peer-reviewed archival journal publication.

B.4 (B3_Final RPPR_R21_WBV_balance.pdf)

This project provided two postdoctoral scholars and two graduate students with opportunities to learn and develop skills on biomechanical modeling and postural control assessment while quantifying the effects of occupational whole body vibration on postural control measures. They were also supported to disseminate the findings at two international conferences.

C. PRODUCTS

C.1 PUBLICATIONS

Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, monograph) during the reporting period resulting directly from this award?

No

C.2 WEBSITE(S) OR OTHER INTERNET SITE(S)

NOTHING TO REPORT

C.3 TECHNOLOGIES OR TECHNIQUES

NOTHING TO REPORT

C.4 INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

Have inventions, patent applications and/or licenses resulted from the award during the reporting period? No

If yes, has this information been previously provided to the PHS or to the official responsible for patent matters at the grantee organization? No

C.5 OTHER PRODUCTS AND RESOURCE SHARING

NOTHING TO REPORT

D. PARTICIPANTS

D.1 WHAT INDIVIDUALS HAVE WORKED ON THE PROJECT?

Commons ID	S/K	Name	Degree(s)	Role	Cal	Aca	Sum	Foreign Org	Country	SS
JAYKIM	Y	Kim, Jeong Ho	PHD	PD/PI	0.0	0.0	1.0			NA
DSRINI	Y	Srinivasan, Divya	PHD	PD/PI	0.0	0.0	1.0			NA
	N	Kia, Kiana	PhD	Staff scientist (Doctoral level)	4.5	0.0	0.0			NA
	N	Park, Jang Ho	PhD	Staff scientist (Doctoral level)	4.5	0.0	0.0			NA

Glossary of acronyms:
S/K - Senior/Key
Cal - Person Months (Calendar)
Aca - Person Months (Academic)
Sum - Person Months (Summer)
Foreign Org - Foreign Organization Affiliation
SS - Supplement Support
RS - Reentry Supplement
DS - Diversity Supplement
OT - Other
NA - Not Applicable

D.2 PERSONNEL UPDATES

D.2.a Level of Effort

Not Applicable

D.2.b New Senior/Key Personnel

Not Applicable

D.2.c Changes in Other Support

Not Applicable

D.2.d New Other Significant Contributors

Not Applicable

D.2.e Multi-PI (MPI) Leadership Plan

Not Applicable

E. IMPACT

E.1 WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES? Not Applicable
E.2 WHAT IS THE IMPACT ON PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES THAT FORM INFRASTRUCTURE? NOTHING TO REPORT
E.3 WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER? Not Applicable
E.4 WHAT DOLLAR AMOUNT OF THE AWARD'S BUDGET IS BEING SPENT IN FOREIGN COUNTRY(IES)? NOTHING TO REPORT

G. SPECIAL REPORTING REQUIREMENTS SPECIAL REPORTING REQUIREMENTS

G.1 SPECIAL NOTICE OF AWARD TERMS AND FUNDING OPPORTUNITIES ANNOUNCEMENT REPORTING REQUIREMENTS

NOTHING TO REPORT

G.2 RESPONSIBLE CONDUCT OF RESEARCH

Not Applicable

G.3 MENTOR'S REPORT OR SPONSOR COMMENTS

Not Applicable

G.4 HUMAN SUBJECTS

G.4.a Does the project involve human subjects?

Not Applicable

G.4.b Inclusion Enrollment Data

File(s) uploaded:
CumulativeInclusionEnrollmentReport.pdf

G.4.c ClinicalTrials.gov

Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?

G.5 HUMAN SUBJECTS EDUCATION REQUIREMENT

NOT APPLICABLE

G.6 HUMAN EMBRYONIC STEM CELLS (HESCS)

Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?

No

G.7 VERTEBRATE ANIMALS

Not Applicable

G.8 PROJECT/PERFORMANCE SITES

Not Applicable

G.9 FOREIGN COMPONENT No foreign component
G.10 ESTIMATED UNOBLIGATED BALANCE Not Applicable
G.11 PROGRAM INCOME Not Applicable
G.12 F&A COSTS Not Applicable

Cumulative Inclusion Enrollment Report

This report format should NOT be used for collecting data from study participants.

Study Title: Effects of Multi-axial Whole Body Vibrations on Postural Stability

Comments:

Racial Categories	Ethnic Categories									Total
	Not Hispanic or Latino			Hispanic or Latino			Unknown/Not Reported Ethnicity			
	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	
American Indian/ Alaska Native										0
Asian	3	4								7
Native Hawaiian or Other Pacific Islander										0
Black or African American		2								2
White	7	7								14
More Than One Race										0
Unknown or Not Reported				2						2
Total	**10**	**13**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**25**

I. OUTCOMES

I.1 What were the outcomes of the award?

Prolonged exposure to Whole Body Vibration (WBV) has been associated with loss of postural stability and thereby increased risks of falling. Previous studies have shown that off-road heavy equipment vehicle operators are exposed to multi-axial WBV which has significant fore-aft (x-axis) and/or lateral (y-axis) vibration as compared to on-road vehicle operators who WBV exposure are predominantly on the vertical axis. These multi-axial components of WBV can have additional adverse effects on the vestibular system and thereby reduce postural stability. However, the nature of the additional impact of multi-axial WBV exposure on postural stability is poorly understood. Therefore, this study quantified the relative impacts of vertical-dominant and multi-axial WBV exposures on postural control and evaluated the effectiveness of an intervention (i.e., multi-axial active suspension seat) to mitigate WBV-related postural control impairment.

These are some of our main findings:

• Prolonged sitting without WBV (i.e., control condition) by itself impaired postural control.
• Both vertical-dominant and multi-axial WBV negatively affected postural control.
• While limited differences on postural control measures were observed between the two types of WBV exposures, off-road vehicles' multi-axial WBV had greater impact on some of the postural control measures compared to on-road vehicles' vertical-dominant WBV.
• The multi-axial active suspension seat did not exhibit superior performance in mitigating the effects of multi-axial WBV on postural control when compared to the vertical-axial passive suspension seat.
• The study suggests that taking even a brief break of 30 minutes could offer drivers the advantage of recovering from potential postural control impairments associated with both WBV and prolonged sitting.