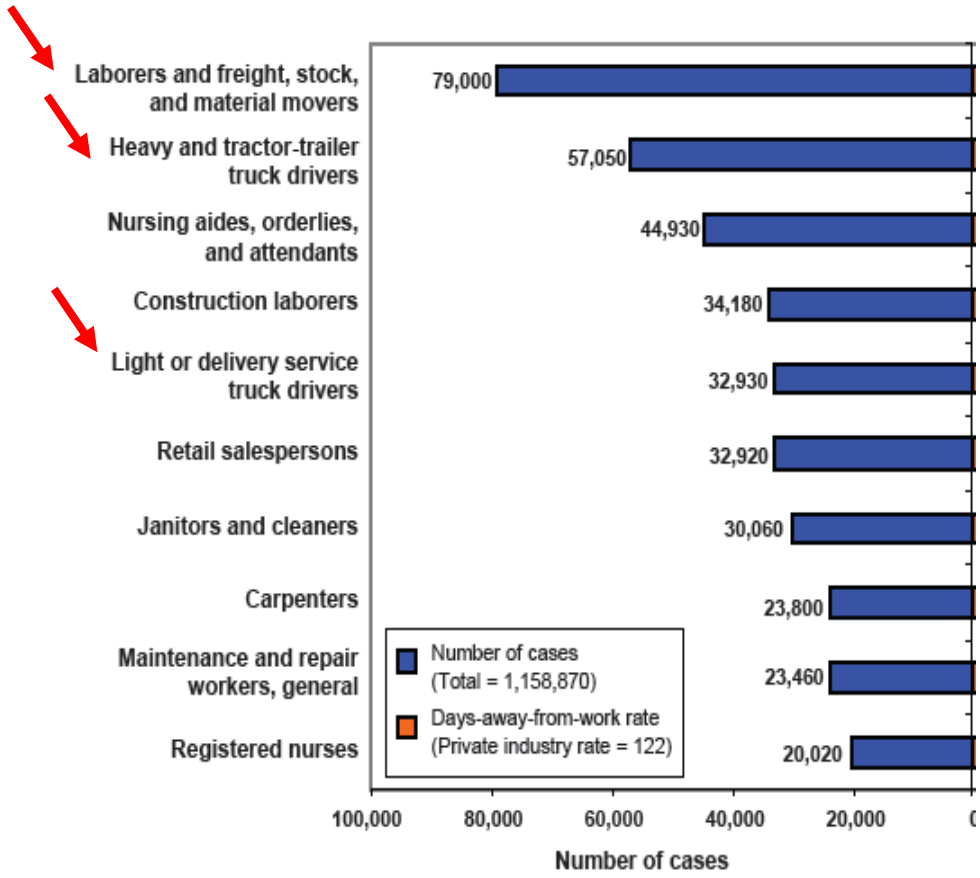
Adverse Outcomes Associated with Occupational Exposures to Whole Body Vibration:

Making a Health, Safety and Business Case

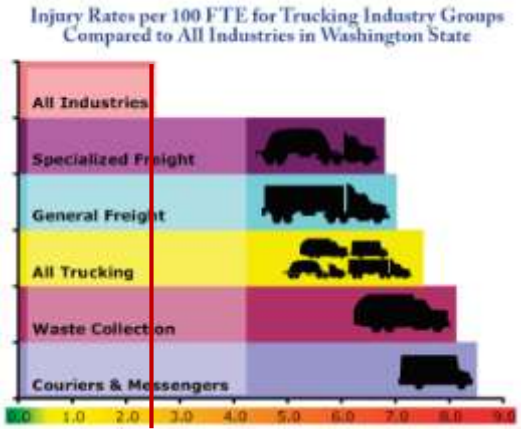
September 16, 2020

Peter Johnson | Professor Emeritus | Department of Environmental and Occupational Health Sciences

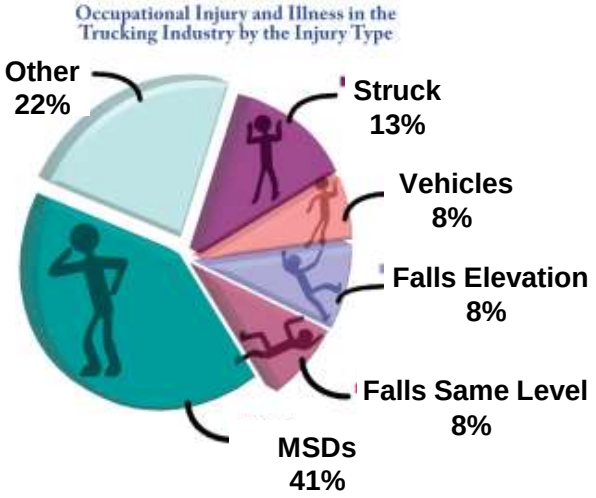
Number and incidence rate for occupations with 20,000 or more injuries and illnesses



These 10 occupations have 20,000 or more cases of injuries and illnesses. Laborers and freight, stock, and material movers had 79,000 cases of injuries and illnesses and a rate of 434 per 10,000 workers. Nursing aides, orderlies, and attendants had a higher rate, 465 per 10,000 workers, but fewer cases.

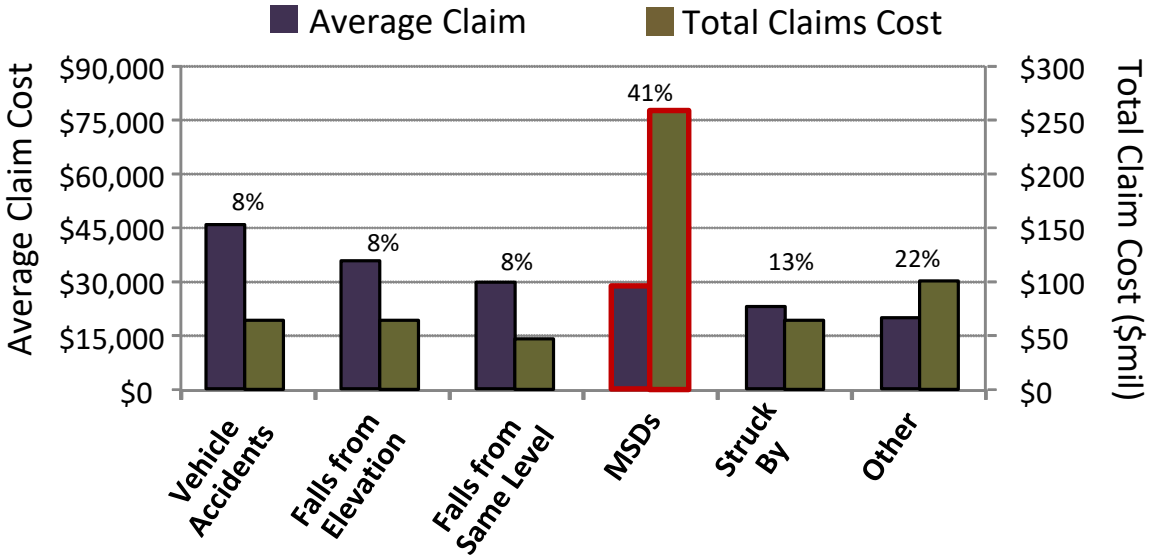


Injury rates in driving over 3x higher



Musculoskeletal disorders (MSDs) single largest component of claims

Average MSD Claim is $30k



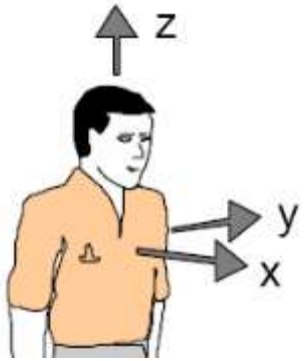
Whole Body Vibration (WBV) and Low Back Pain Development

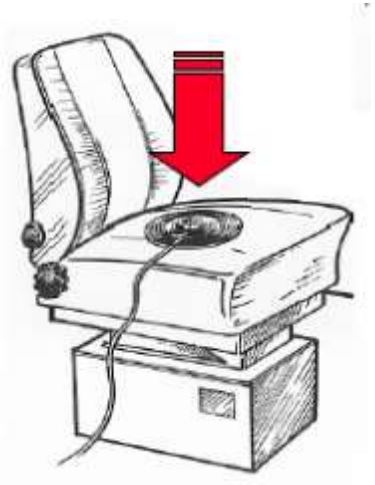
- Back injuries are most significant non-lethal medical condition affecting the US workforce.
- Epidemiological studies have consistently linked WBV to low back pain/injury
- Dose response relationship established (~**5 years** of exposure)

www.sflorg.com/spacenews/images/imsn091206_01_04.jpg

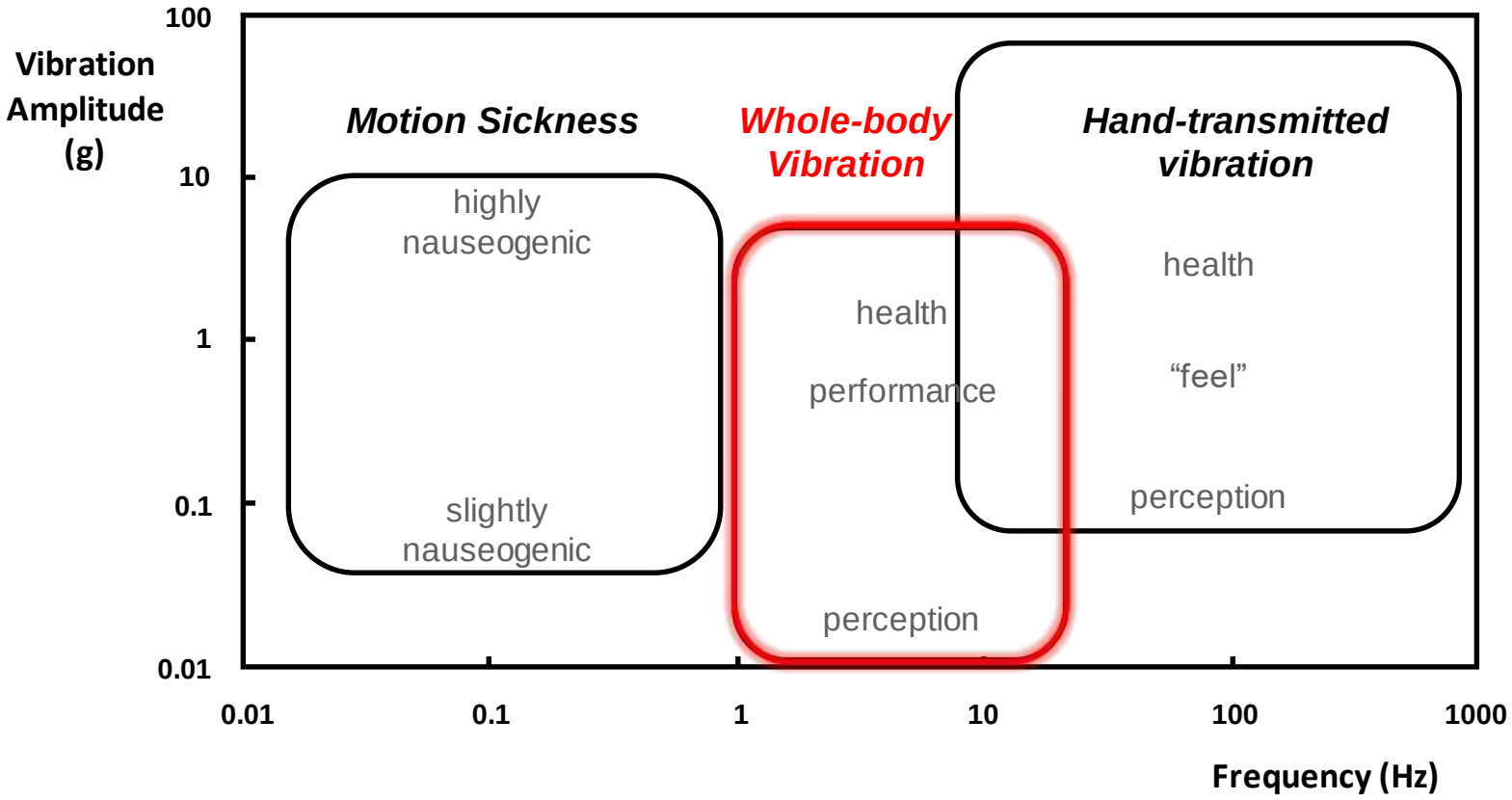
What Is Whole-Body Vibration?

- **Objective measure to describe operator motion**
- **Vector quantity with:**
  - Magnitude or intensity of motion
  - Direction of motion
- **Usually characterized by:**
  - Frequency: How often the operator vibrates (units: Hz)
  - Acceleration: How motion of the operator changes over time (units: m/s^2)





How Vibration Affects Humans

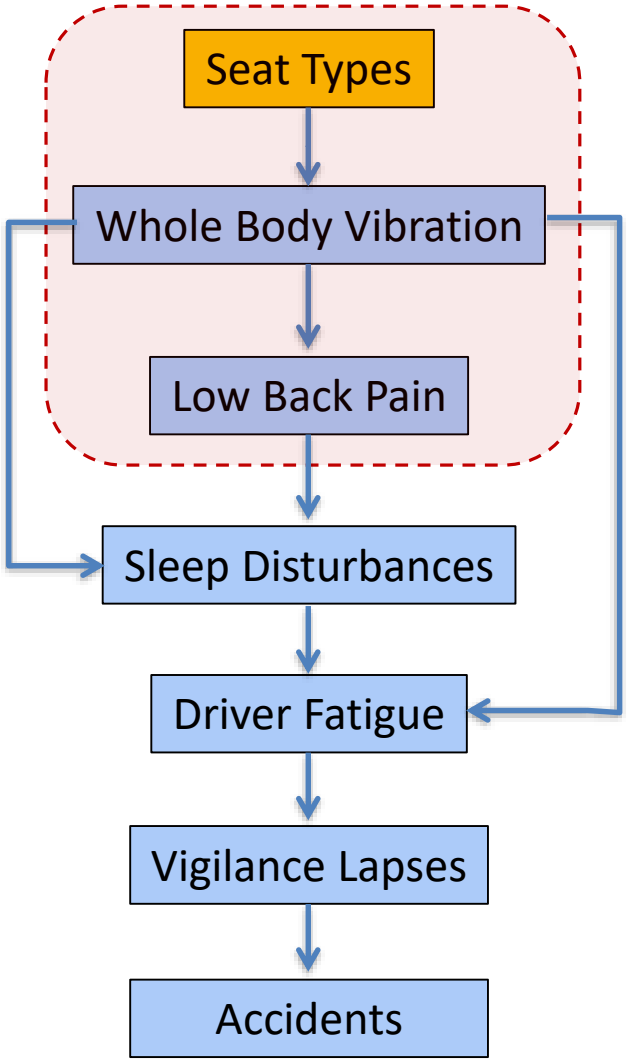


Source: Derived from Neil J. Mansfield, Human Response to Vibrations, CRC Press, 2005, p.7.

Causality Map

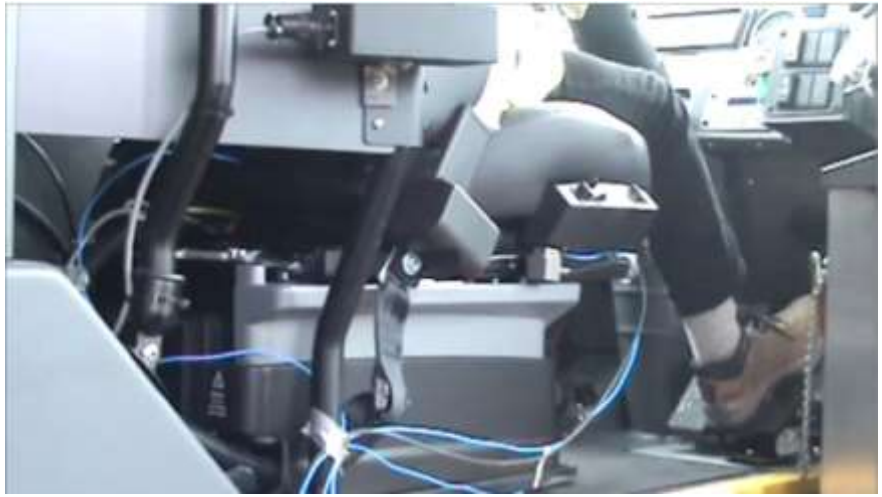
Industry Standard Seat

Enhanced Seats

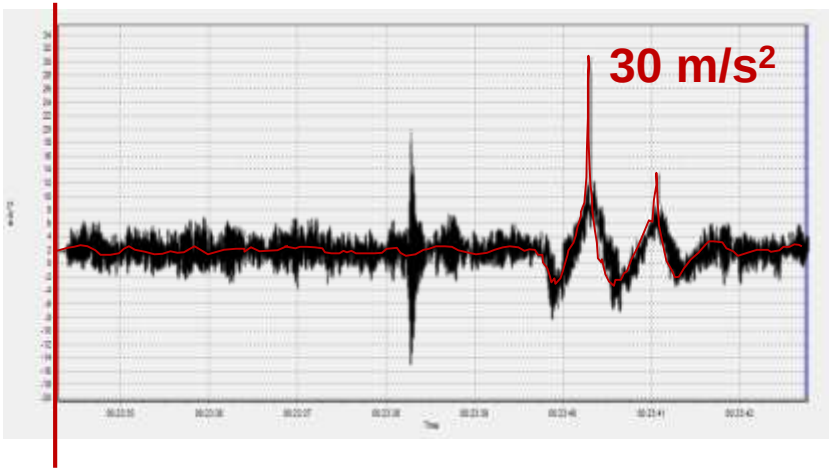


Comparison of Seat Suspension Technologies

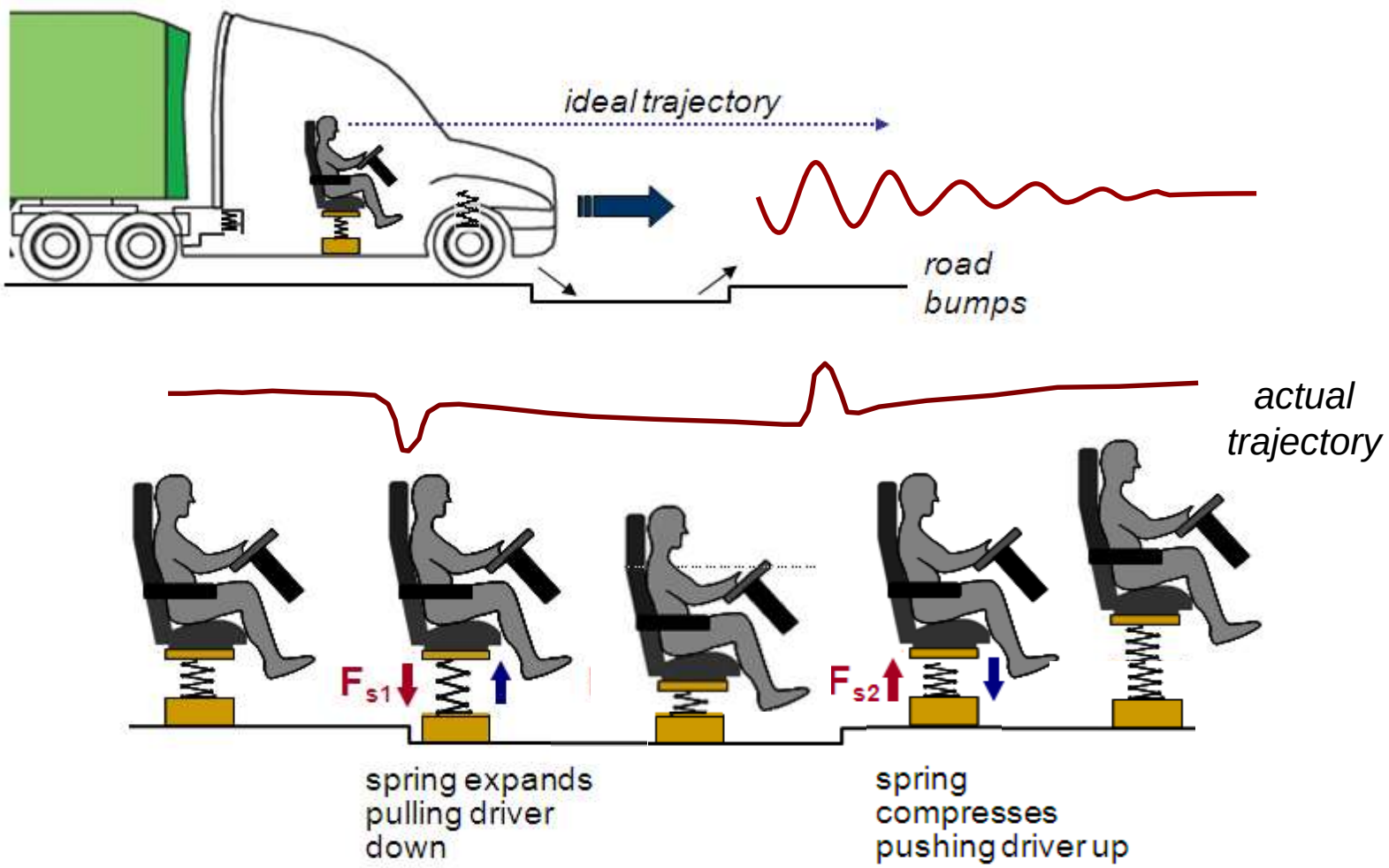
	1950's	1960's	1980's
			
	Static	**Mechanical Suspension**	**Air-Ride**
Uses	On-Road	On/Off Road	Many
Cost	Low	+ Moderate	++ Moderate
Pros	?	?	?
Cons	?	?	?



Air Suspension Seat



Challenges with Passive Suspension Seats



Amplify vibration when going over small perturbations at moderate to high speed

Seat Suspension Design Matters

Occupational Medicine 2012;62:519–524
Advance Access publication on 9 July 2012 doi:10.1093/occmed/kqs096

Whole-body vibration exposure in metropolitan bus drivers

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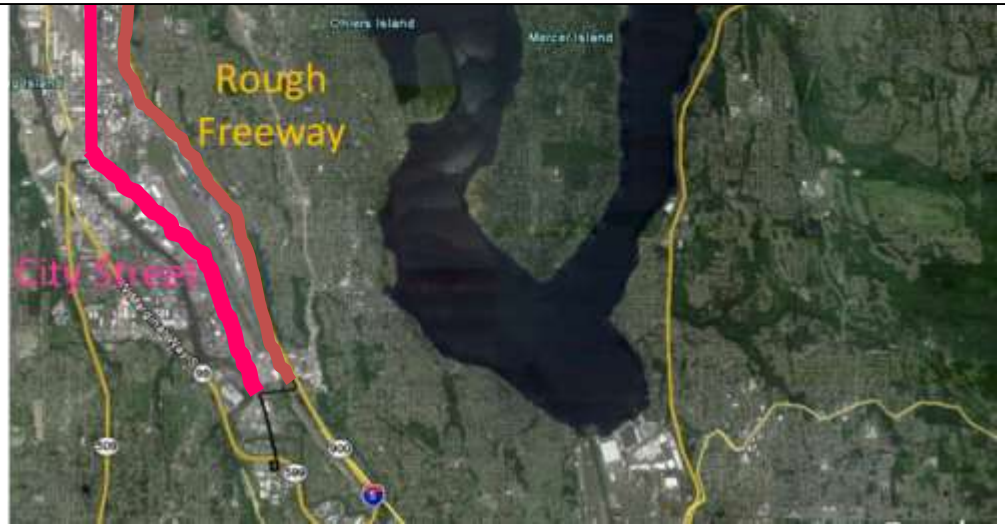
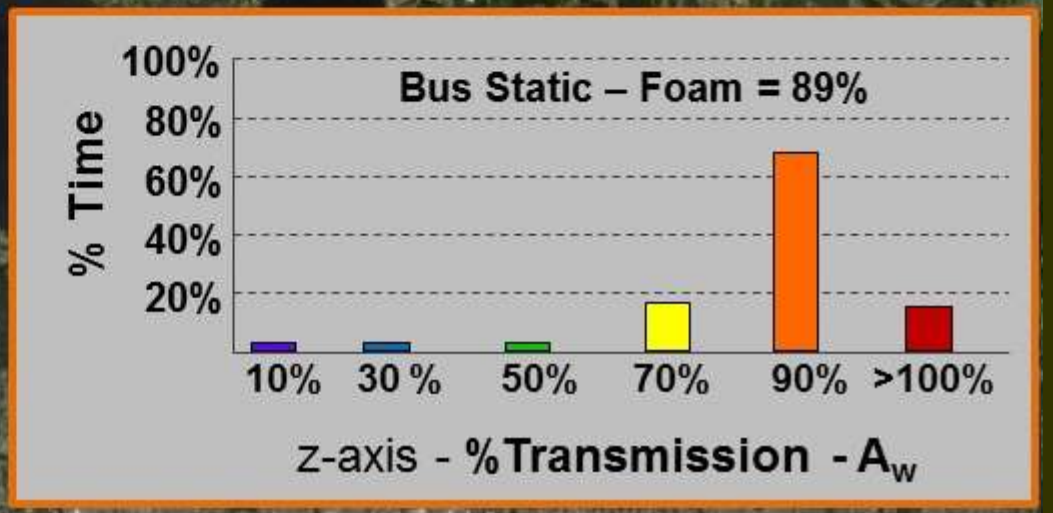


Vibration Transmitted from Bus Floor to Seat of the operator



Take Home Messages

- The current air-suspension seat may not be optimized for on-road vehicles
- The current long travel suspension seat may not be necessary for on-road vehicles

Comparison of Seat Suspension Technologies

	1950's	1960's	1980's	2010
				
	Static	**Mechanical Suspension**	**Air-Ride**	**ElectroMech Active**
Uses	On-Road	On/Off Road	Many	Trucking
Cost	Low	+ Moderate	++ Moderate	+High
Pros	+++ WBV Not Weight Dependent	++ WBV	+++ WBV Less Weight Dependent	WBV?
Cons	Bumps	Weight Dependent Amplify WBV	Amplify WBV	Currently On-Road

New Truck Seats are Available

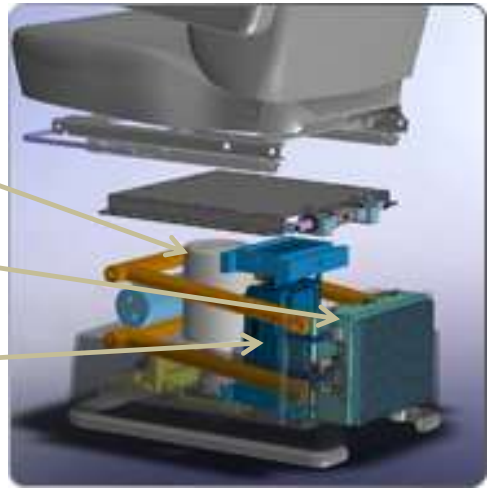
- **To combat challenges with air-ride seats, new "active suspension" truck driver seats have recently been developed and introduced**

New Technology Seats:

① **Air suspension system like a conventional truck seat**

② **Sensor in seat base, microprocessor processes seat sensor data in order to cancel forces in real time**

③ **Linear electromagnetic actuator counteracts forces**

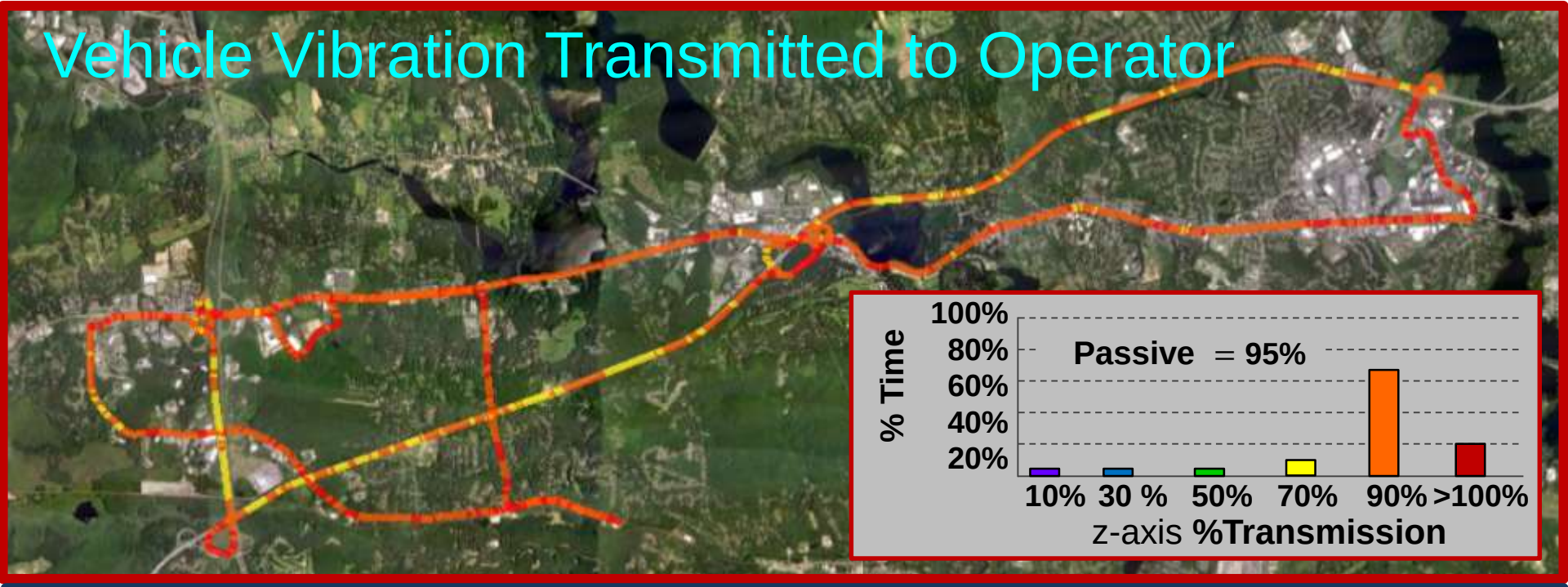


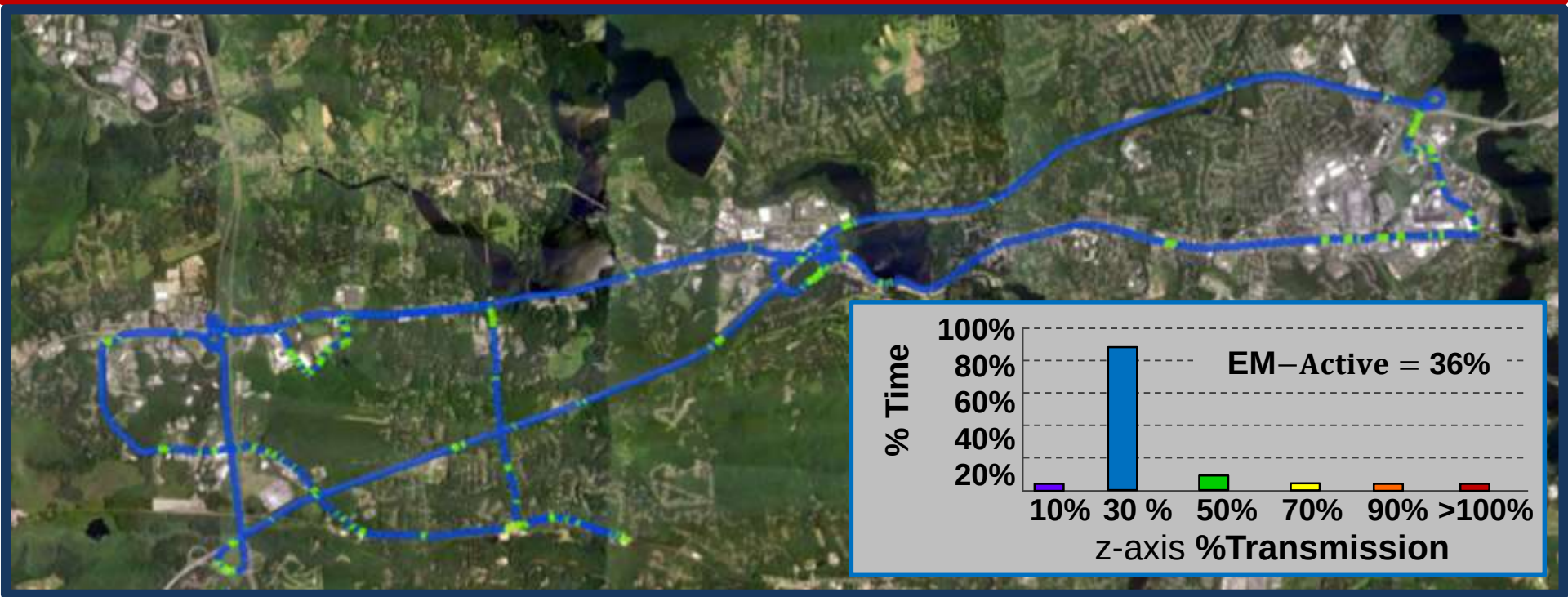
- **The UW has tested the new technology seats in a group of 16 truck drivers**

Passive

EM Active

Vehicle Vibration Transmitted to Operator





Annals of Work Exposures and Health, 2018, Vol. 62, No. 8, 1000–1011
doi: 10.1093/annweh/wxy063
Advance Access publication 17 July 2018
Original Article

BOHS The Chartered Society for Worker Health Protection

OXFORD

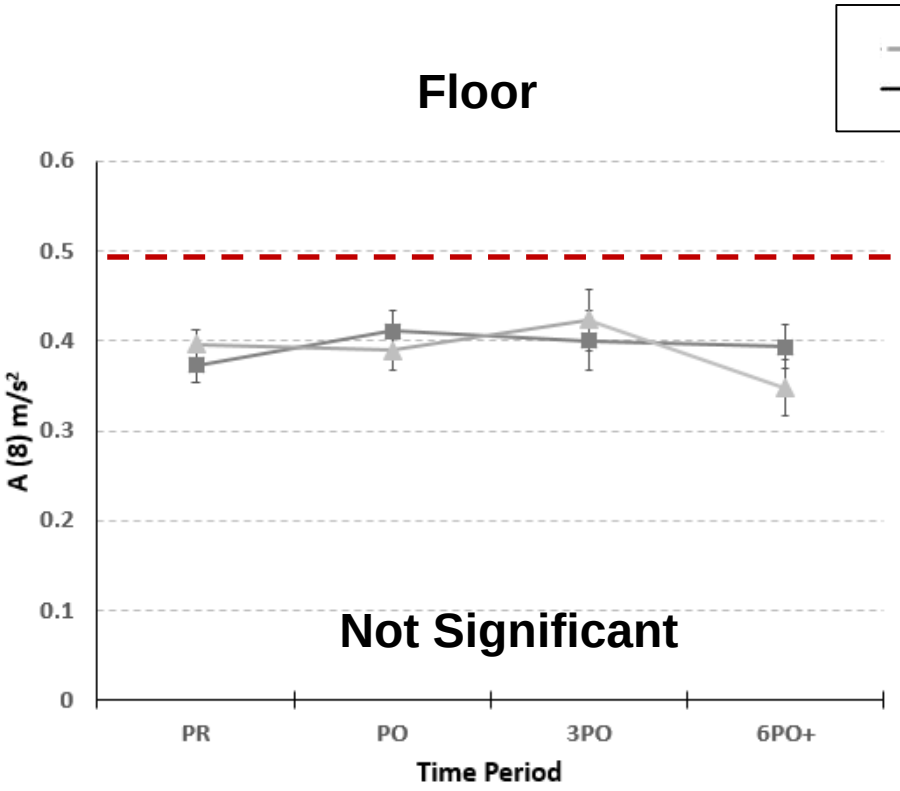
Original Article

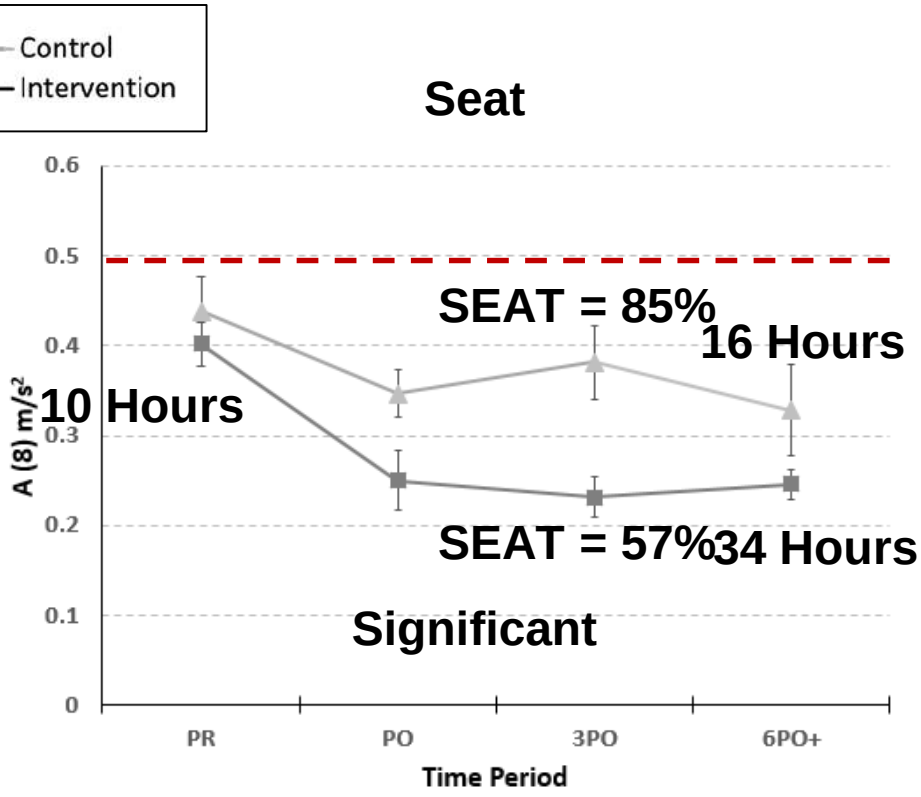
A Randomized Controlled Trial of a Truck Seat Intervention: Part 2—Associations Between Whole-Body Vibration Exposures and Health Outcomes

Jeong Ho Kim[1,*], Monica Zigman[2], Jack T. Dennerlein[3,4] and Peter W. Johnson[2]

Results

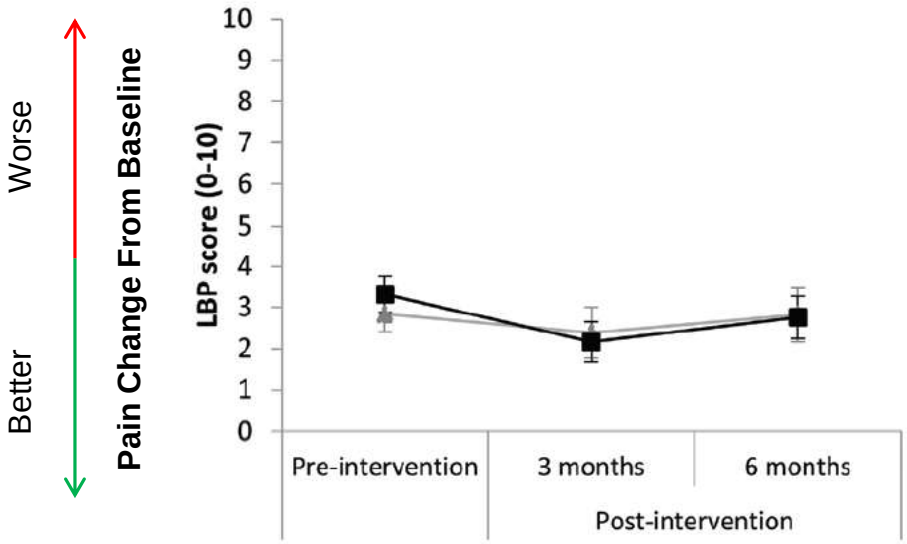
Average Weighted Vibration – A(8)

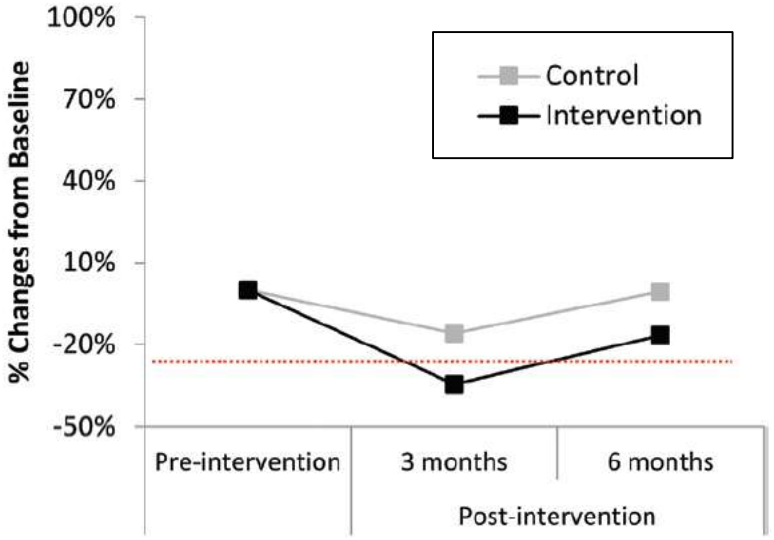




Results

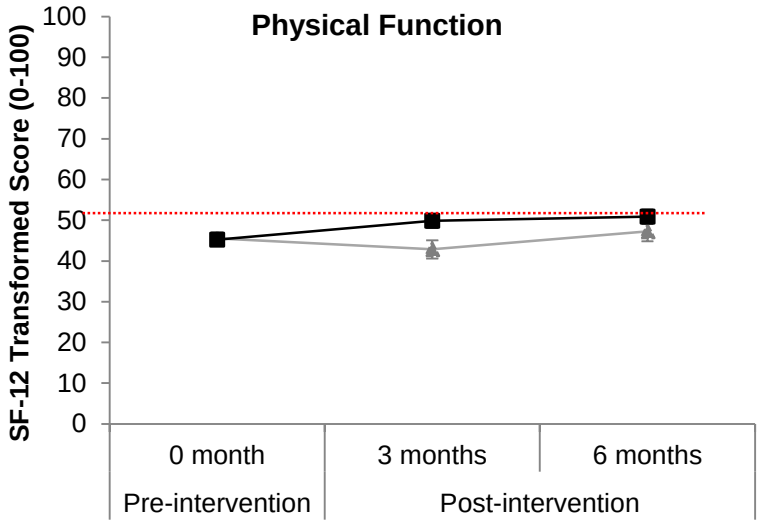
Low Back Pain Results

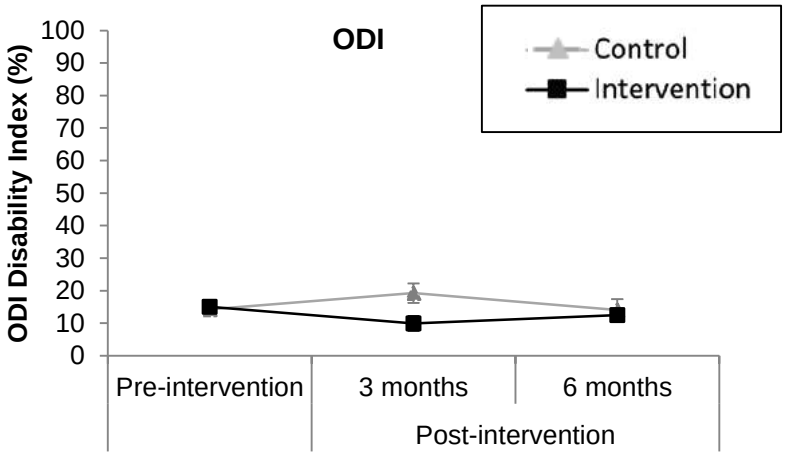


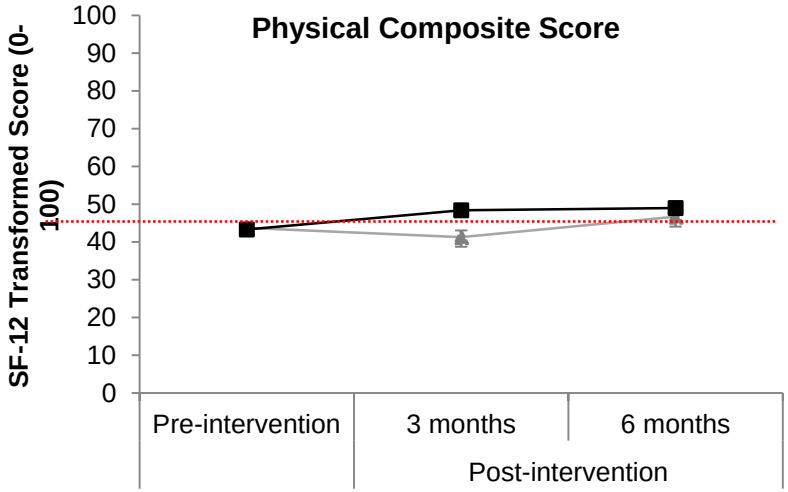


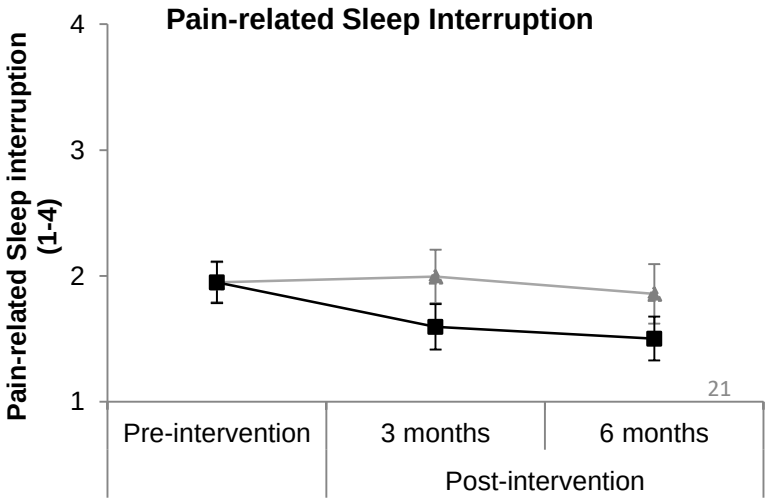
Not Significant

Red line - Clinical Significance.


Physical Function
SF-12 Transformed Score (0-100)
100
90
80
70
60
50
40
30
20
10
0
0 month
3 months
6 months
Pre-intervention
Post-intervention

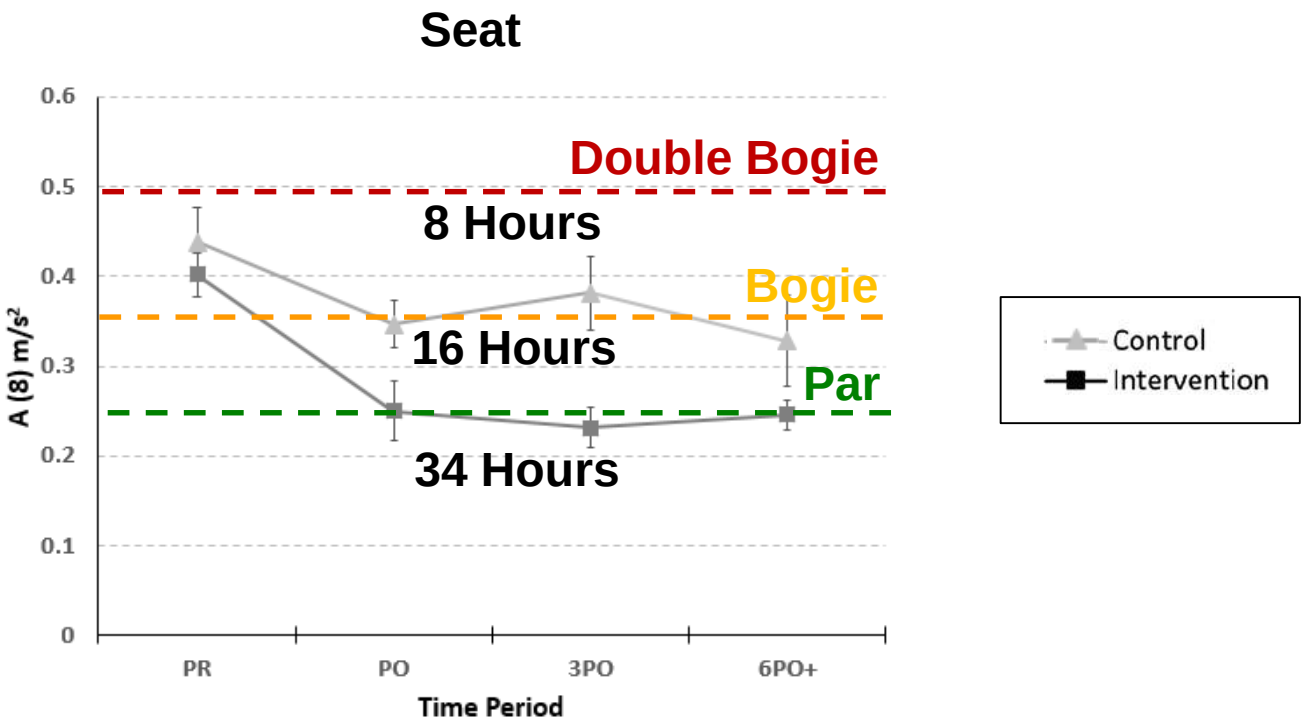

ODI
Control
Intervention
ODI Disability Index (%)
100
90
80
70
60
50
40
30
20
10
0
Pre-intervention
3 months
6 months
Post-intervention


Physical Composite Score
SF-12 Transformed Score (0-100)
100
90
80
70
60
50
40
30
20
10
0
Pre-intervention
3 months
6 months
Post-intervention


Pain-related Sleep Interruption
Pain-related Sleep interruption (1-4)
4
3
2
1
Pre-intervention
3 months
6 months
Post-intervention

Results

Average Weighted Vibration – A(8)



SCHOOL OF PUBLIC HEALTH
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Whole Body Vibration Exposures: Assessing the Cost and Health Effects of Different Seats

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David Veenstra[4], Peter W. Johnson [,2,3]

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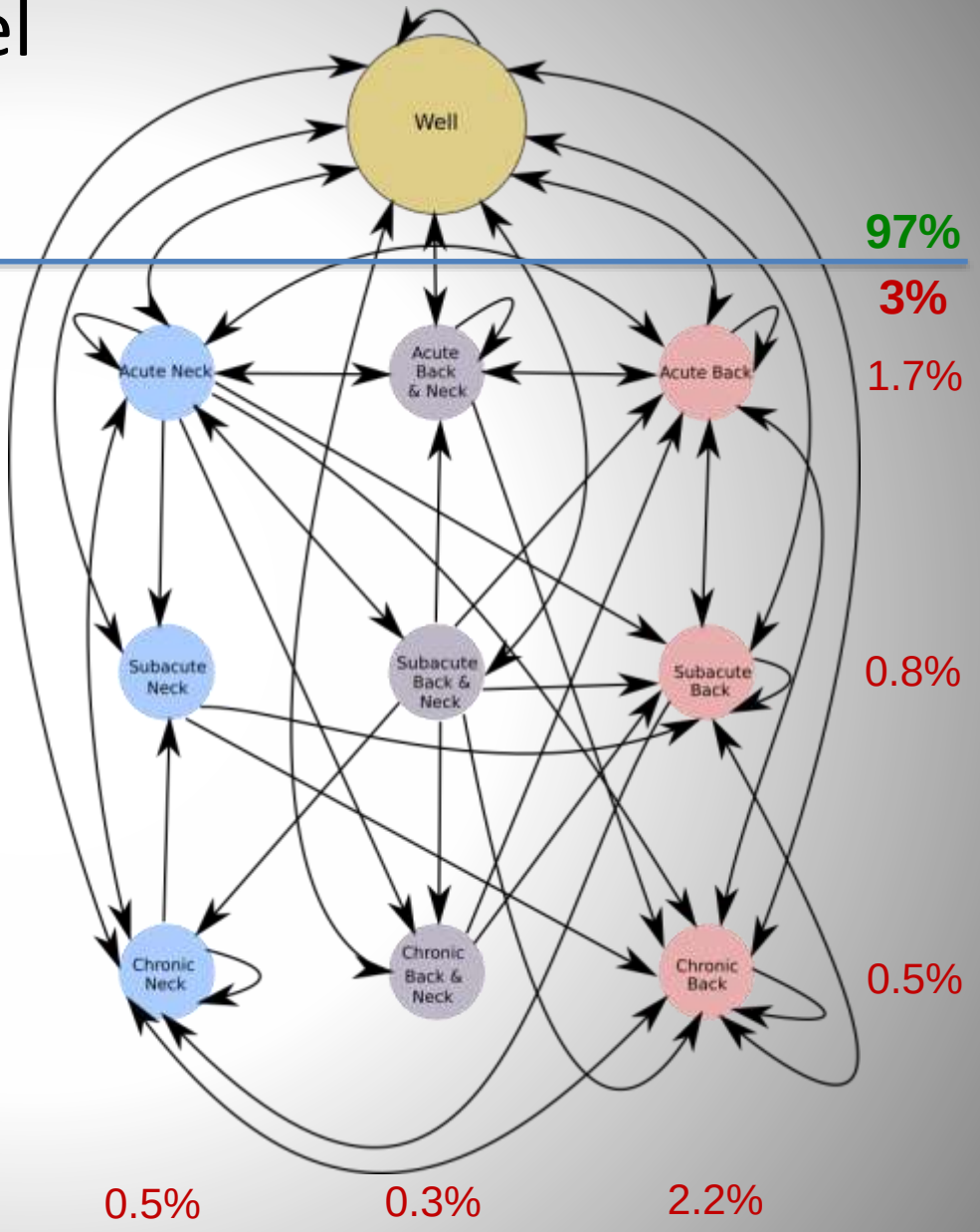
What would be a cost-effective seating strategy to reduce LBP and costs among Metro bus drivers?

1. **Existing – keeping and maintaining seats over the 15 year life of a bus**
2. **Periodic Replacement of Passive-Suspension Seats**
   - Current passive-suspension seats wear out easily
   - High level of maintenance
3. **Static Seat**
   - Less expensive and reduced maintenance
   - Comparable vibration exposures to passive-suspension seat
4. **Active-suspension driver seat**
   - More expensive than existing passive-suspension seats
   - Reduces vibration exposures approx. 50%
   - Shown to reduce LBP by up to 30%

Methods: Markov Model

- **15-year worker comp claim database for King County Metro (1999-2013)**
- **15 cycles = 15 year typical life of a Metro bus**
- **1 year cycles**
- Models the **likelihood of filing a worker comp claim** each year
- **Circles represent health states**
- **Arrows represent allowed transitions**



Cost and Utility Inputs

Cost Inputs - 1,500 Bus Fleet where buses are maintained for 15 years

- Existing: **$2,805 + $950 maintenance years 5 and 10**
- Static Seat: **$2,500 + $300 maintenance years 5 and 10**
- Active-Suspension Seat: **$3,995 + $950 maintenance years 5 and 10**
- Seat Replacement every 5 years: **$6,415 + no maintenance costs**

- Mean Claim Costs
  - Adjusted for claim maturity
  - Adjusted for inflation to 2015 dollars (CPI)
  - Indirect Costs Modifier: **1.22** (claims administration and taxes)

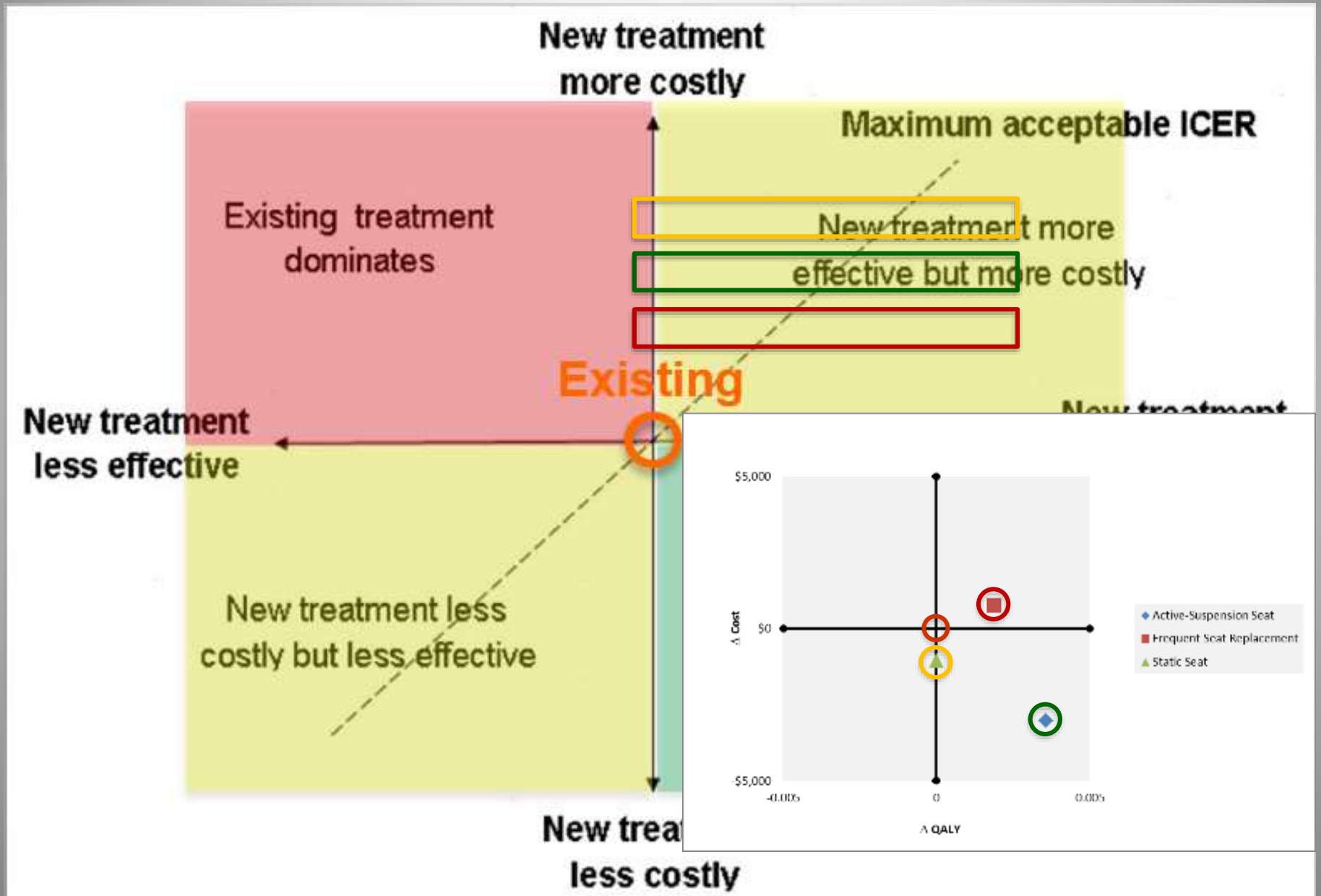
Utility Inputs

- Back Pain: **0.67,** Neck Pain: **0.62,** Back & Neck Pain: **0.62,** No Claim: **0.82**
- Utilities weighted for the expected time in each health state
- Willingness to pay $50,000 per Quality Adjusted Life Year (QALY)

Savings

- Existing: **no savings**
- Static Seat: **-$650 maintenance years 5 and 10, no effect on "well" to "claim" states**
- Active-Suspension Seat: **-15% in transition probabilities from "well" to "claim" states**
- Seat Replacement every 5 years: **-5% in transition probabilities "well" to "claim" states**

Model Results



Results Summary

- Active-Suspension Seat **cost-effective**
  - Health benefits outweigh seat costs
    potential cost-savings of $4.5 million
  - Would be cost-effective down to a %5 reduction in WBV-related claims
- Static Seat **cost-effective**
  - Reduced maintenance costs save $2 million
  - Is unlikely to reduce claim rates
- Frequent Seat Replacement **not cost-effective**
  - Increased seat costs
  - Seat costs outweigh heath benefit cost $2.5 million

Safety & Trucking

ERGONOMICS, 2018
VOL. 61, NO. 4, 528–537
https://doi.org/10.1080/00140139.2017.1372638

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Check for updates

The impact of different seats and whole-body vibration exposures on truck driver vigilance and discomfort

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ABSTRACT

Laboratory studies have shown that exposure to whole-body vibration (WBV) increases physical and mental fatigue, which are common issues professional drivers face. The objective of this study was to determine whether altering WBV exposures had any effect on driver vigilance and discomfort. A repeated measures crossover design of five truck drivers with regular 10-h routes was used. Active and passive suspension truck seats were evaluated. For each seat, WBV exposures were measured. Participants completed a discomfort questionnaire and a reaction time task before and after their shift for two weeks, one week per seat. Compared with the passive seat, the active seat significantly reduced WBV exposures, decrements in the optimal and mean reaction times ($p = 0.02$, 0.047, respectively), and discomfort in the lower back and wrist(s)/forearm(s) ($p < 0.01$, 0.01, respectively). Study results indicated that reducing WBV helps reduce discomfort and maintain vigilance, which may improve drivers' health and reduce the risk of truck collisions.

Practitioner Summary: The active suspension seat used in this study reduced truck drivers' exposure to whole-body vibration (WBV) by over 33% in relation to their current industry standard passive suspension seat. This study demonstrated that reducing truck drivers' exposure to WBV reduced fatigue and discomfort development over a workday.

ARTICLE HISTORY
Received 7 March 2017
Accepted 21 August 2017

KEYWORDS
Whole-body vibration; attention and vigilance; back pain; transportation safety

Overview of Driver Fatigue

- 47% truck drivers have fallen asleep at the wheel of their truck and 25% have done so in the past year (McCartt et al., 2000).
- The human and economic cost of commercial vehicle crashes is significant.
  - The average comprehensive cost of a police-reported crash involving a large truck is $91,112.
  - $3.6 million per crash involving fatality (FMCSA, 2005).

Psychomotor Vigilance Task (PVT)

- Sustained reaction time task
  - Subjects are instructed to respond as they see numbers or a dot appear on a screen.
  - The stimulus appears randomly every 2-10 seconds for 5-10 minutes for a total of 40-80 trials.
- Gold standard to test alertness
- Reliability and validity

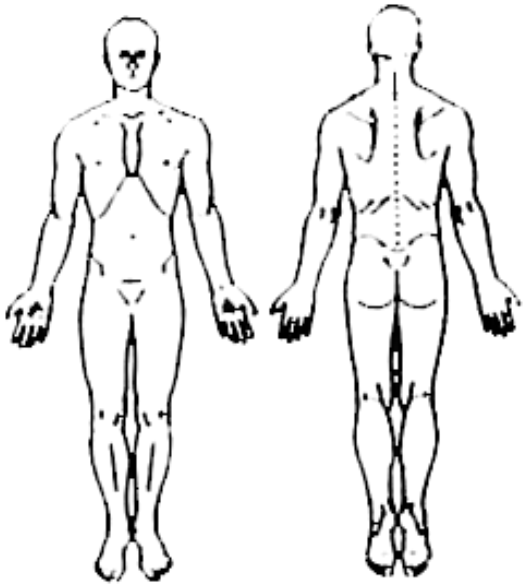
Dependent Variables

Whole-body Vibration (WBV)

1. A(8) (m/s^2)
2. VDV(8) ($m/s^{1.75}$)
3. Vector sum

Psychomotor Vigilance Task (PVT)

1. Mean response time (RT)
2. Fastest 10% RT
3. Number of Lapses (>500ms)



10-point pain scale

1. Shoulder(s)
2. Wrist(s)/Forearm(s)
3. Knee(s)
4. Ankle(s)/Feet
5. Neck
6. Upper Back
7. Lower Back
8. Buttocks/Legs

Study Design

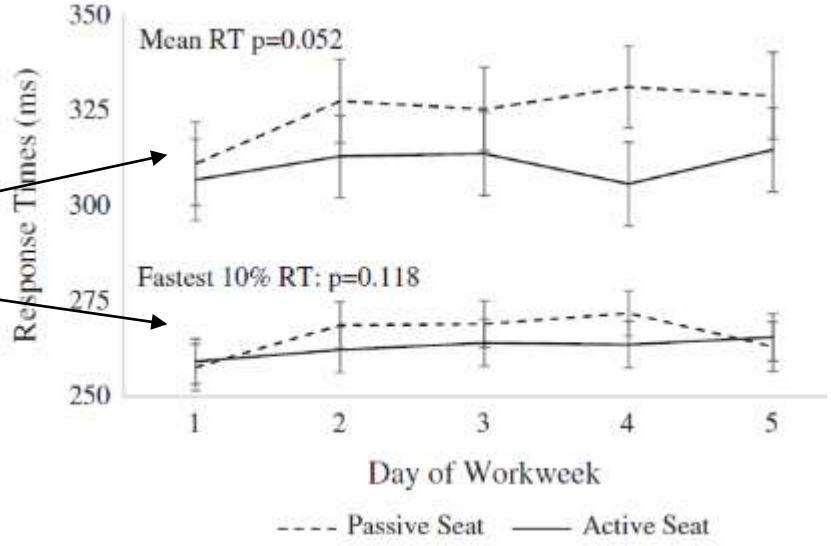
Repeated measures crossover design (n=5)

	Existing Seat							Vibration Cancelling Seat				
	1	2	3	4	5	6	7	8	9	10	11	12
Pre-Shift	PVT and Questionnaire					Seat Installation		PVT and Questionnaire				
Work Shift	WBV Measurement							WBV Measurement				
Post-Shift	PVT and Questionnaire							PVT and Questionnaire				

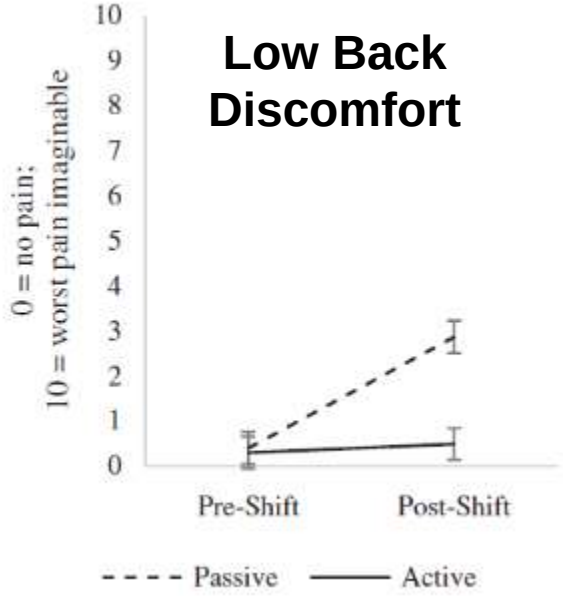
Results

Reaction Times

PVT outcome metric	Seat type	Time of day: Pre-shift	Time of day: Post-shift		*p*-Value
Mean RT (ms)	Passive	315 (10.5)	334 (10.5)	Δ=19	0.047
	Active	305 (10.5)	316 (10.5)	Δ=11	
Fastest 10% RT (ms)	Passive	260 (5.1)	272 (5.5)	Δ=12	0.02
	Active	261 (5.5)	265 (5.5)	Δ= 4	



Low Back Discomfort



UNIVERSITY of WASHINGTON

A Field Study Comparing PVT Results Across Four Seats

Fangfang Wang
University of Washington

Objectives

- Determine whether shift-long WBV exposure affects a truck driver's PVT performance.
- Determine whether differences in WBV exposures across four seats differentially affect vigilance in a real-world field setting.

Four Seats

Seat 1
National
Premium
Existing seat

Seat 2
Sears Elite
80

Seat 3
Isringhausen
6860

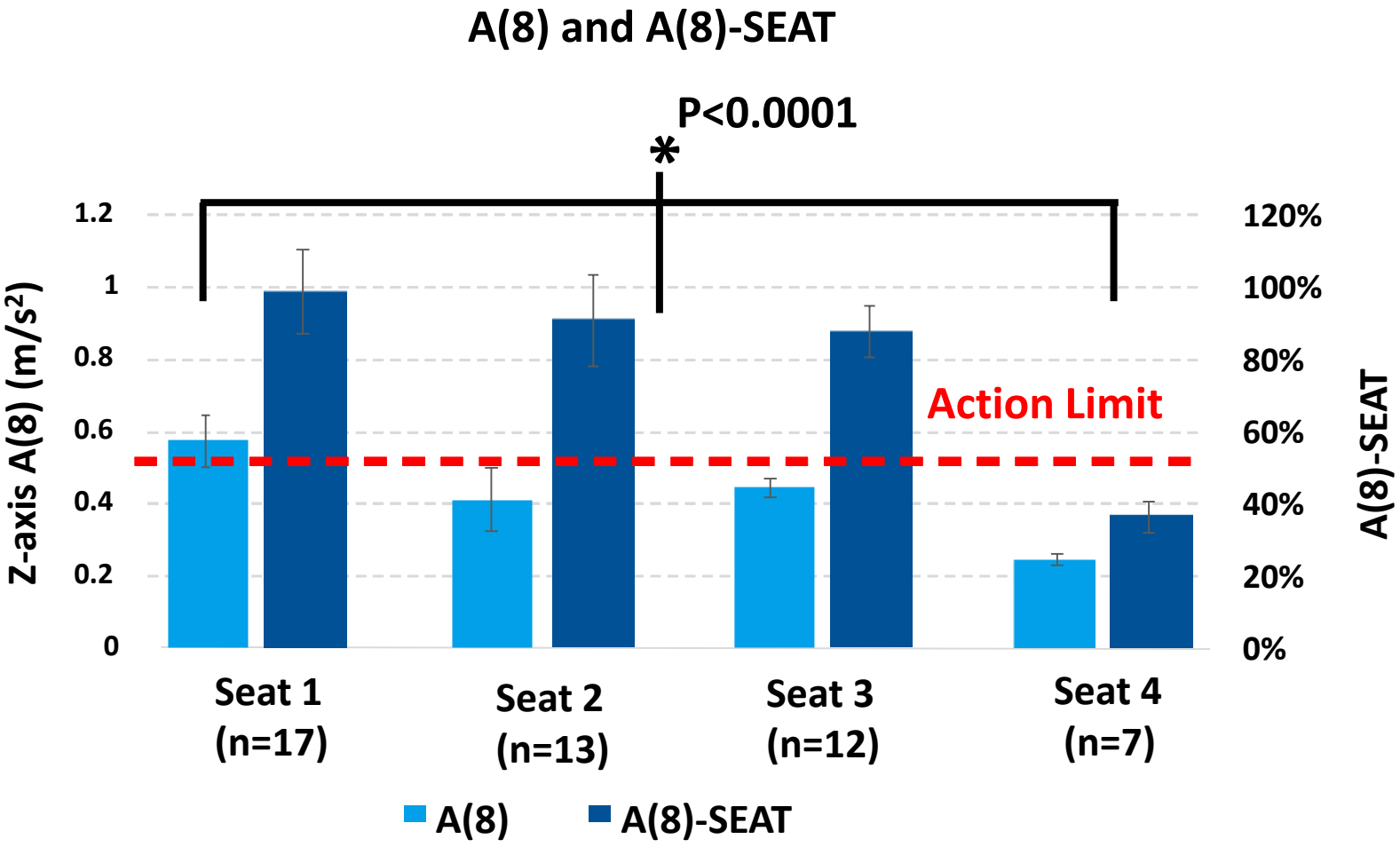
Seat 4
Bose Ride
Active Suspension

WBV Measurement

- 11 hour full-shift WBV exposure
- ISO 2631-1 standards
- Tri-axial seat and floor vibration at 1280 Hz
- GPS recording speed and location

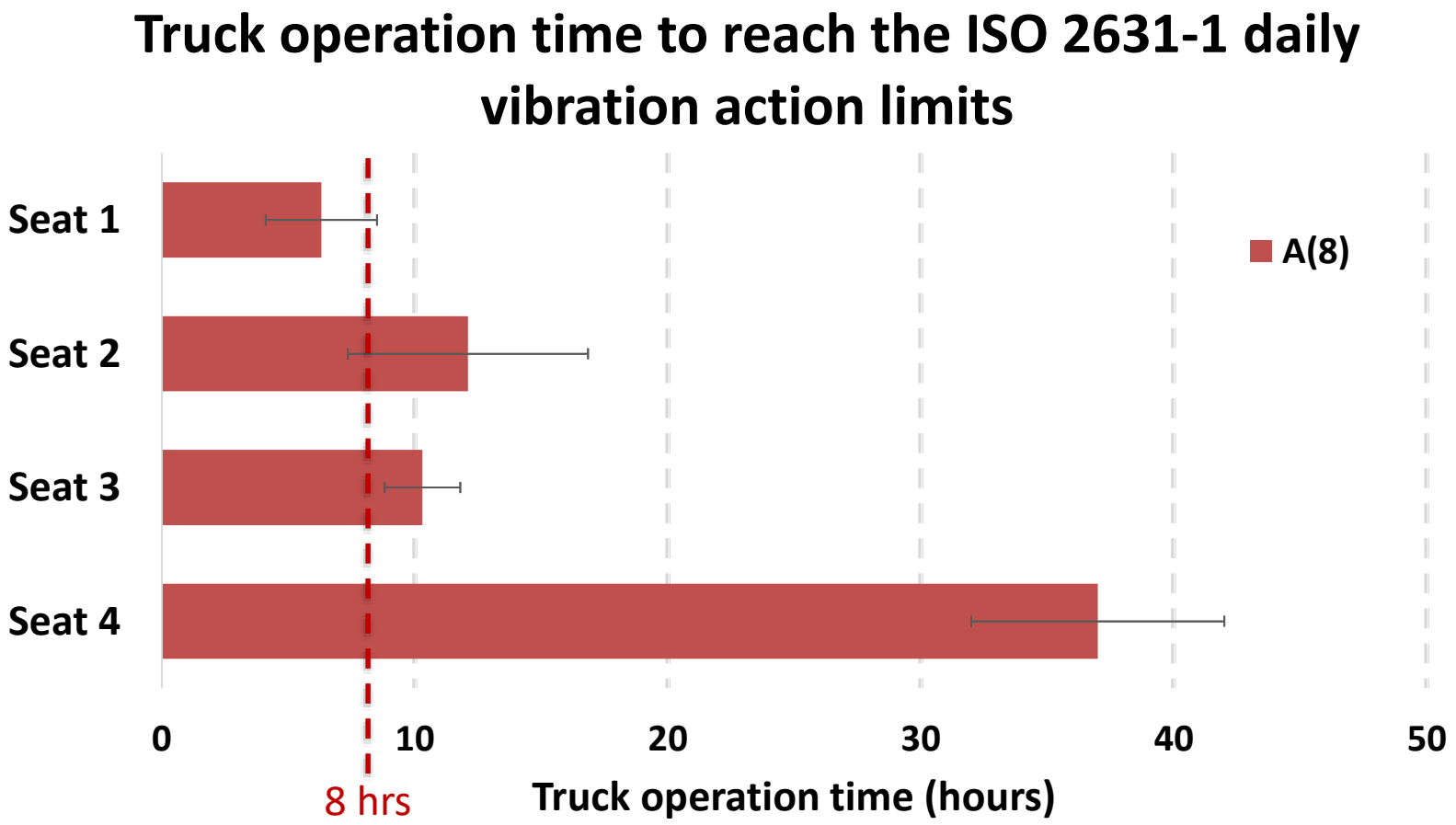
Typical route of a 11-hour shift

Results- A(8) WBV Exposures of Whole Route



Median (±IQR) z-axis seat-measured A(8) WBV exposures of whole routes

Results - Truck Operation Time



Two Seat groups

Seat 1
National Premium

Original Seat

Seat 2
Sears Elite 80

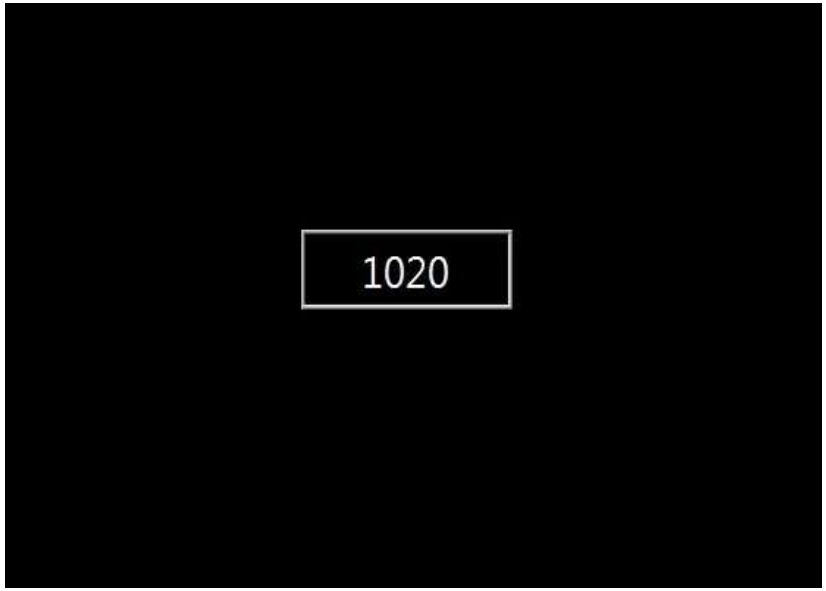
Seat 3
Isringhausen 6860

Seat 4
Bose Ride

Enhanced Seats

PVT Performance Measures

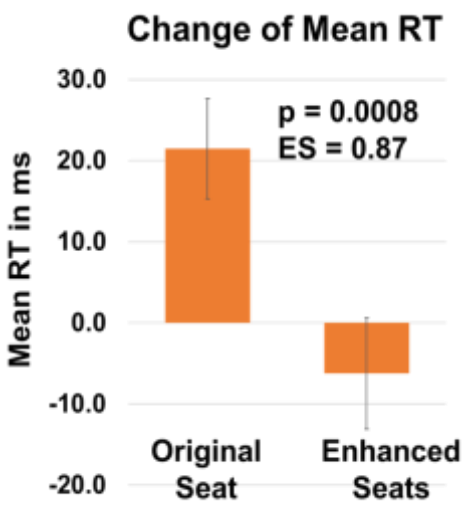
- 5-minute, in-truck tablet-based PVT immediately before and after the 11 hour shift.
  - Mean reaction time (RT) , lapse percentage (RT > 500 ms), mean fastest 10% RT, mean slowest 10% RT .

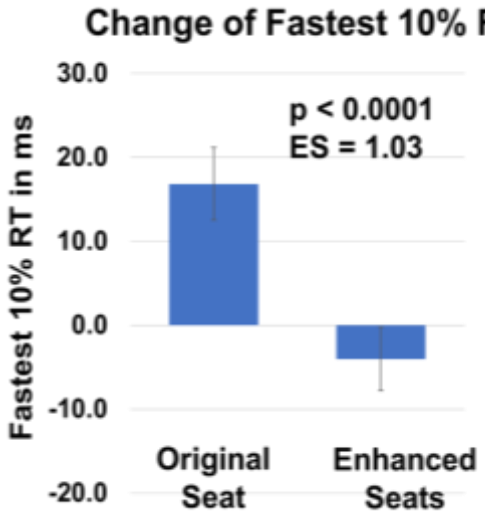


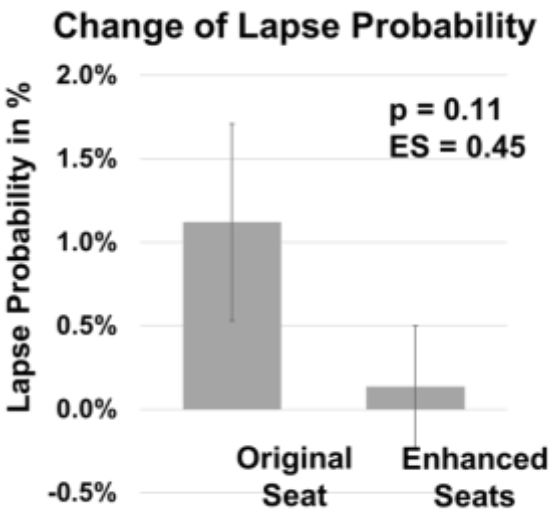
During PVT task

Results: PVT outcomes

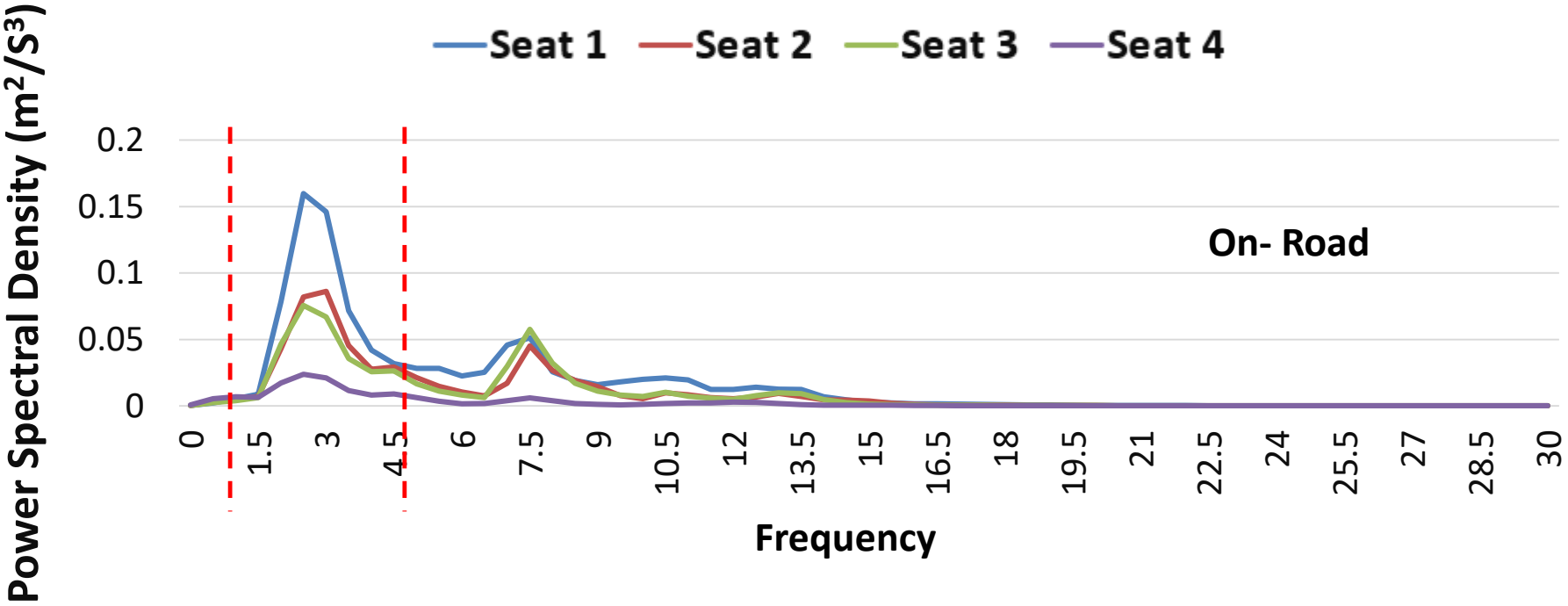
- Significant differences in Mean RTs and Fastest 10% RTs in the between seats.
  - Degrading RTs from the Original Seat
  - Improving RTs from the Enhanced Seat
- Larger increase in lapse probability with the Original Seat.







Results - Power Spectral Density Analysis



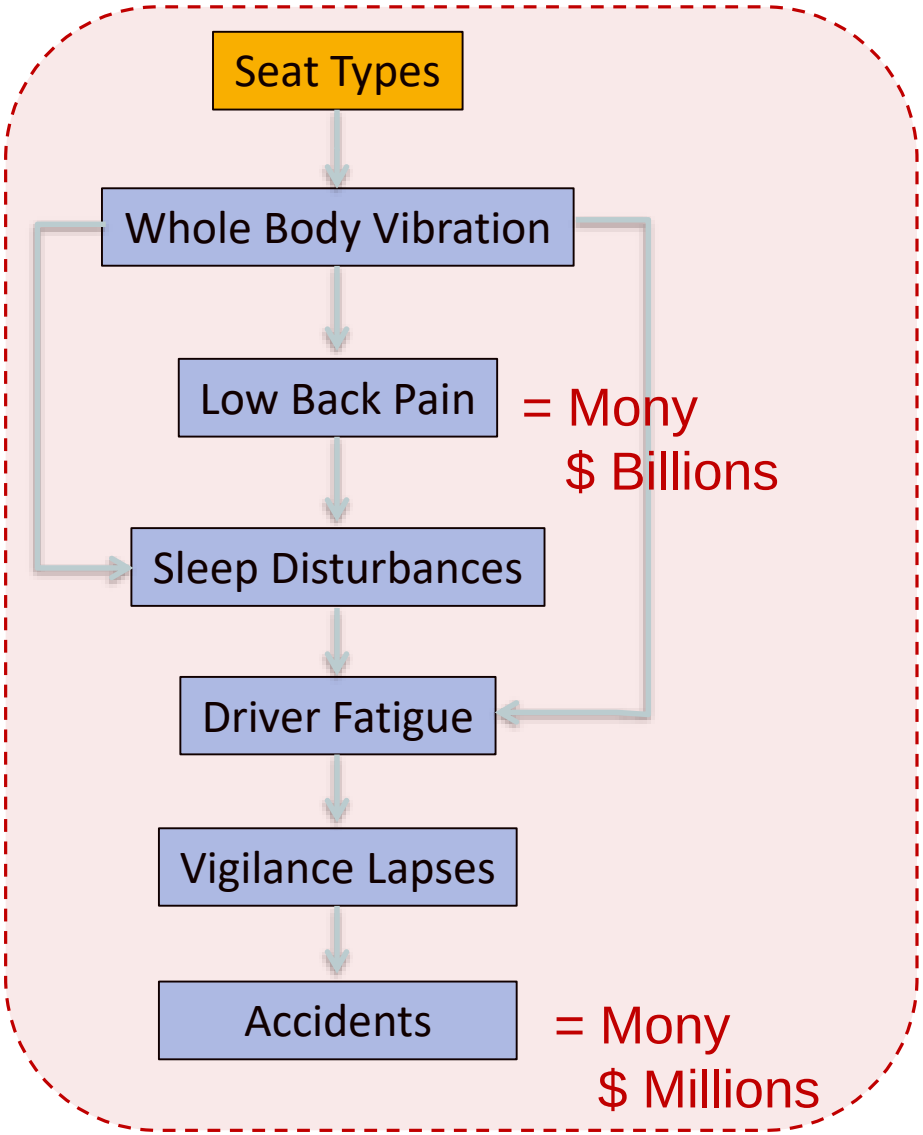
Appears to be a difference in energy at 3 Hz across seats

Causality Map

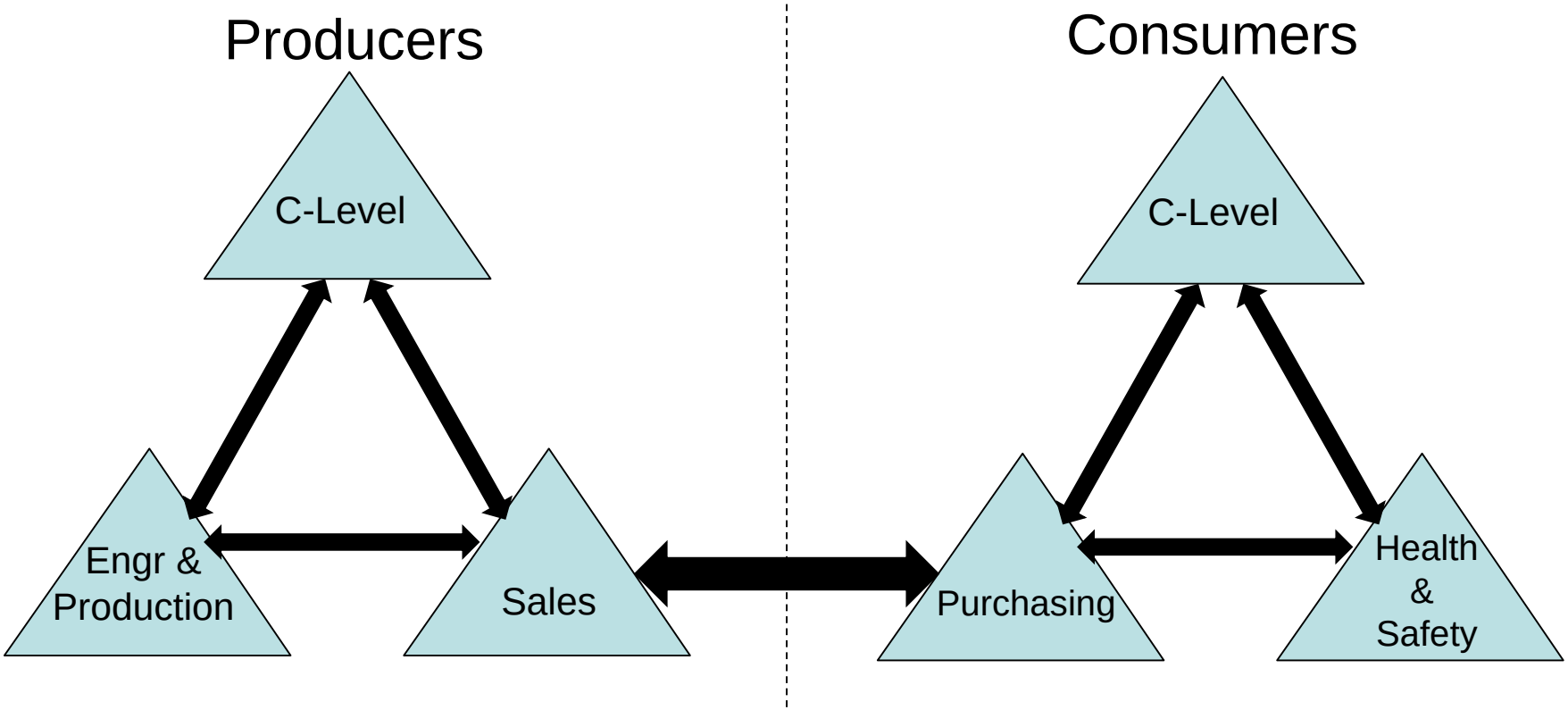
Ergo = Mony

Industry Standard Seat

Enhanced Seats

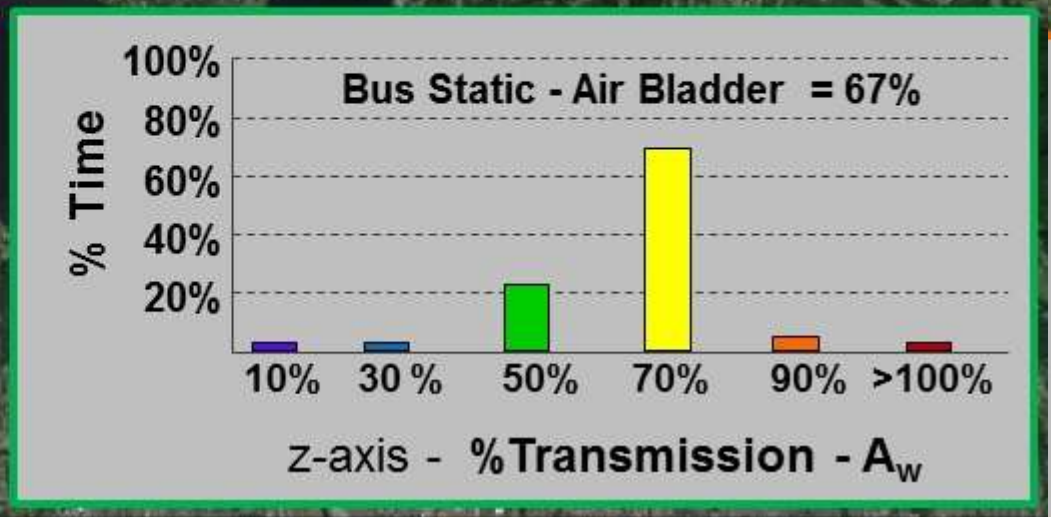


Social Procurement



Train Manufacturers to Produce and Consumers to Buy Quality Seats

Vibration Transmitted from Bus Floor to Seat of the operator



Take Home Messages

- The current, longer travel air-suspension seat may not be optimal and may not needed for on-road vehicles
- Higher performing active suspension seats are available to better protect vehicle operators, but are costly
- New, higher performing passive suspension seats may be available in the future to better protect vehicle operators