

Whole-Body Vibration Exposure in Construction: Examining Acute Effects, Guidelines, and Risk Mitigation Strategies to Prevent MSD and Injuries



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Today's Webinar

1. Examine the acute effects of WBV,
2. Investigate whether established occupational guidelines protect the worker from injurious short-term effects, and
3. Offer considerations to mitigate adverse WBV effects

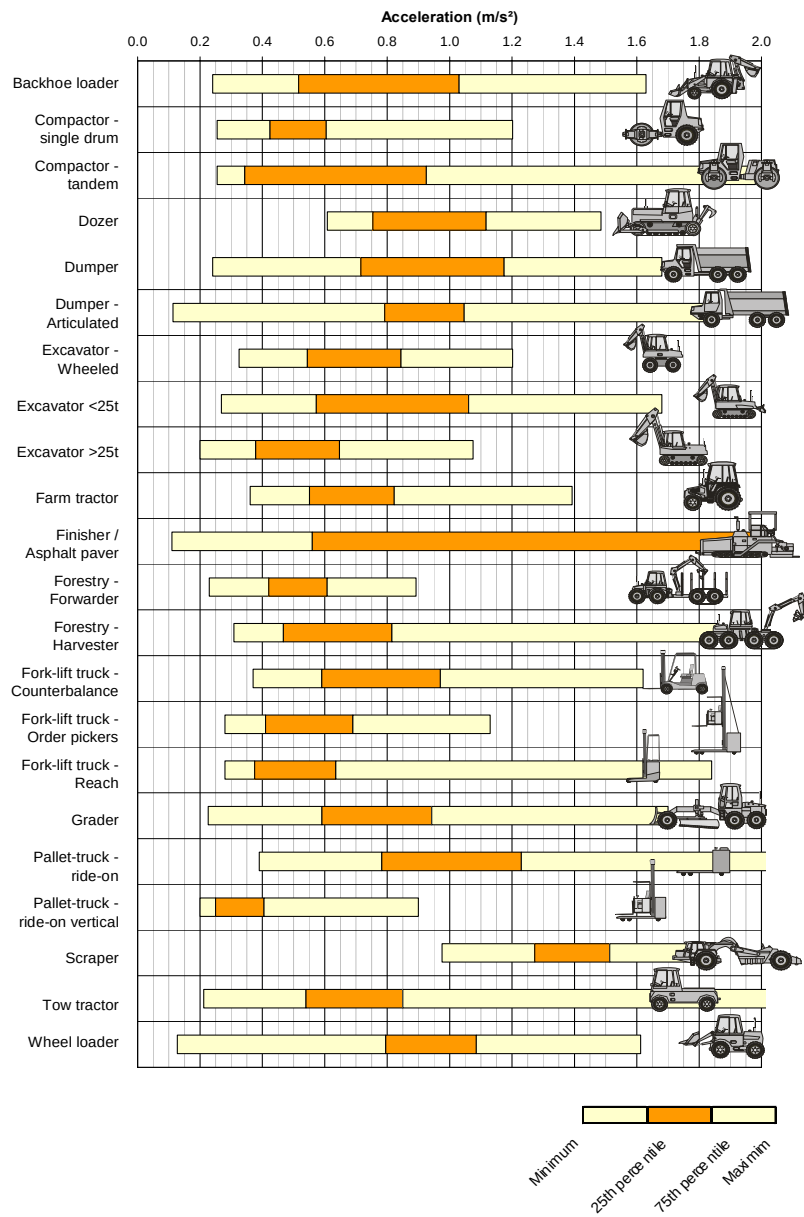


What is whole-body vibration (WBV)?

- Mechanical oscillations of any frequency are transferred to the body.
- Shakes, bumps, and jolts

WBV Parameters	WBV Training and Rehabilitation	Occupational WBV
		
Route of Transmission	Feet	Ischial tuberosity
Duration	~ 5 min	6-8 hours
Frequency	45 Hz	0-20 Hz
Intensity	Varies	Varies
Direction	All directions	All directions





Cann et al 2003

Equipment type (number)	Weighted RMS acceleration (m/s ²)			VDV (m/s ^{1.75})		
	Mean	SD	Range	Mean	SD	Range
Bulldozer						
Large (9)	0.92	0.14	0.6–1.1	9.01	2.60	5.2–12.8
Small (4)	1.11	0.35	0.8–1.4	8.56	2.13	6.4–11.4
Excavator (14)	0.51	0.28	0.1–1.1	5.76	3.28	2.2–15.4
Scraper (4)	1.61	0.30	1.3–2.0	14.9	2.34	12.2–17.9
Grader (4)	0.55	0.15	0.4–0.7	7.25	2.67	3.4–9.2
Skid steer vehicle						
Mini (3)	1.22	0.48	0.7–1.7	11.6	2.15	10.0–14.0
Regular (3)	1.18	0.63	0.5–1.7	9.64	5.11	4.3–14.5
Backhoe	1.05	0.01	1.0–1.1	9.81	0.26	9.6–10.0
Compactors						
Compactor (3)	0.91	0.41	0.5–1.3	7.86	3.45	5.4–10.3
Vibratory compactor (5)	0.64	0.37	0.2–1.0	8.16	3.24	6.2–11.9
Crawler loader (3)	1.01	0.18	0.8–1.1	8.71	1.91	6.6–10.4
Wheel loader (2)	1.16	0.70	0.7–1.7	31.7	A	A
Ride-on power trowel (2)	0.36	0.34	0.1–0.6	8.81	A	A
Variable reach forklift (3)	0.65	0.12	0.5–0.8	5.73	0.27	5.5–5.9
Mobile crane (2)	0.15	0.07	0.1–0.3	0.92	A	A
Off-road dump truck (2)	1.21	0.70	0.7–1.7	17.2	A	A
Forklift (1)	0.37	A	A	3.35	A	A

^AInsufficient data to calculate range and standard deviations due to only one test score.

EU Good Practice Guide, 2006



Health problems associated with WBV:

- Neck problems
- Hearing loss
- Gastrointestinal tract problems
- Spinal degeneration
- Low back pain



WBV and Low Back Pain

- Strong epidemiological evidence linking WBV and low back pain
- Dose-response relationship is seen between WBV and driving-related LBP (Tiemessen, 2008)
- Healthy professional drivers with regular daily vibration exposure are at risk of developing low back symptoms over a two-year follow-up period (Bovenzi, 2010)

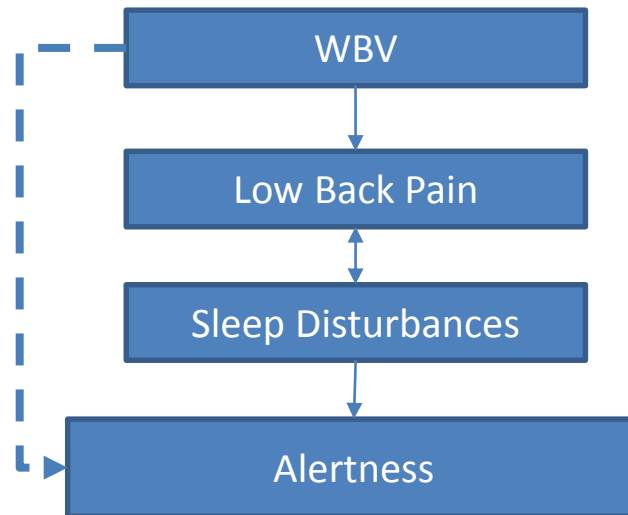


WBV → LBP → Sleep Disturbance Link?

- Systematic review: chronic LBP is associated with sleep disturbances. (Kelly et al., 2011)
- Meta-analysis: 58.7% prevalence of sleep disorders for people with non-specific LBP (Alsaadi et al., 2011)
- Bidirectional relationship



More direct
and acute
relationship?



Acute effects of WBV and alertness

Lab Studies - instrumented measures

- Decreased wakefulness - EEG (Satou et al. 2006; Satou et al. 2007; Azizan & Fard, 2014)
- Increased reaction times and vigilance lapses (Wang & Johnson 2014)

Lab Studies - self-reports

- Conflicted results with self-reported alertness after acute exposures to WBV (Ljungberg, 2010)



Prevalence of Truck Driver Drowsiness

MaCartt et al. 2000 (n=593)

- 47% have fallen asleep at the wheel
- 25% have done so in the past year

Castro et al. 2004 (n=238)

- 56% are tired at least some of the time while driving
- 32% have driven with their eyes closed



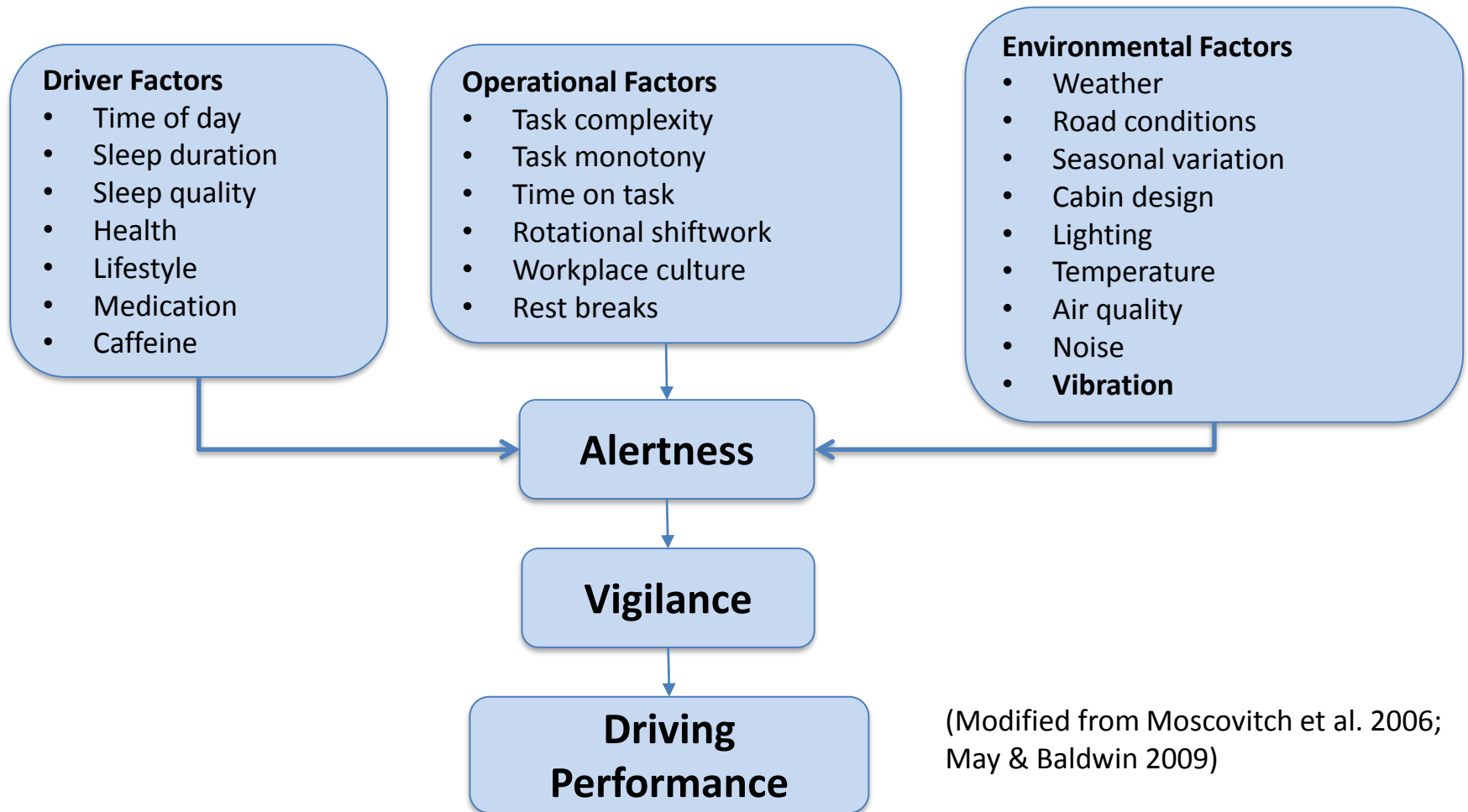
In Canada, driver fatigue accounts for 1.5% of heavy vehicle collisions.



(National Collision Database, 2003-2008)



Factors affecting Driver Fatigue



(Modified from Moscovitch et al. 2006;
May & Baldwin 2009)



Electromagnetically Active Vibration-Cancelling (EVAC)



Study Objectives

1. Determine if an EAVC seat intervention affects vigilance over the course of a workday, and a workweek
2. Determine if drivers find the EAVC seat comfortable.



Methods:

Repeated measures crossover design (n=5)

	Existing Seat							EAVC				
	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				



Independent Variables



Existing



EAVC



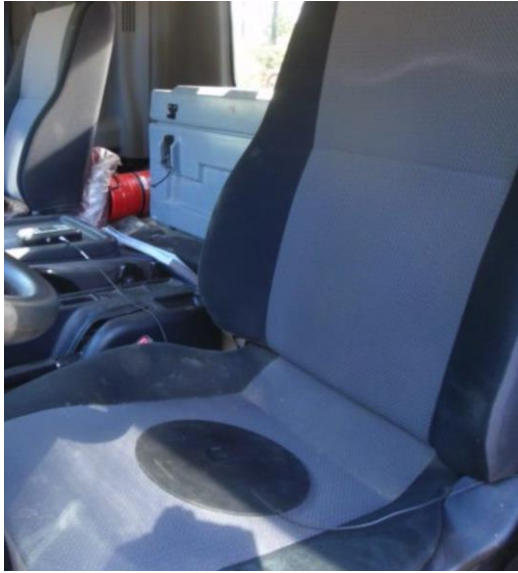
1. Seat Type

2. Time of Day

3. Day of Workweek



Dependent Variables



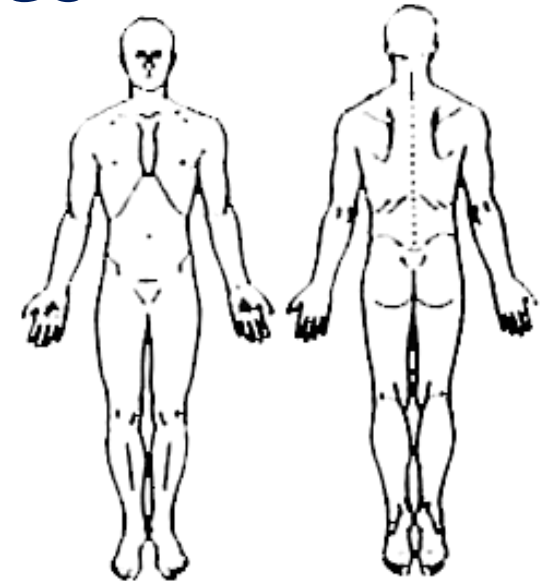
Whole-body Vibration (WBV)

1. $A(8)$ (m/s^2)



Psychomotor Vigilance Task (PVT)

1. Mean response time (RT)
2. Fastest 10% RT
3. Slowest 10% RT
4. Variability
5. Reaction speed ($1/\text{RT}$)
6. Number of Lapses ($>500\text{ms}$)



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



Demographics

Characteristic	Mean	SD	Range
Age (yrs.)	54.4	8.35	(43 - 64)
Height (m)	1.73	0.10	(1.57 - 1.83)
Weight (kg)	108	27.01	(79-140)
Body mass index	35.8	7.67	(27.3 - 44.6)
Time in trucking industry (yrs.)	23.9	13.74	(16 - 44)
Time with company (yrs.)	4.2	4.87	(1.33 - 12.83)
Hours of work per week	57	7.58	(45 - 65)
Hours of driving per week	46.5	7.83	(40 - 60)

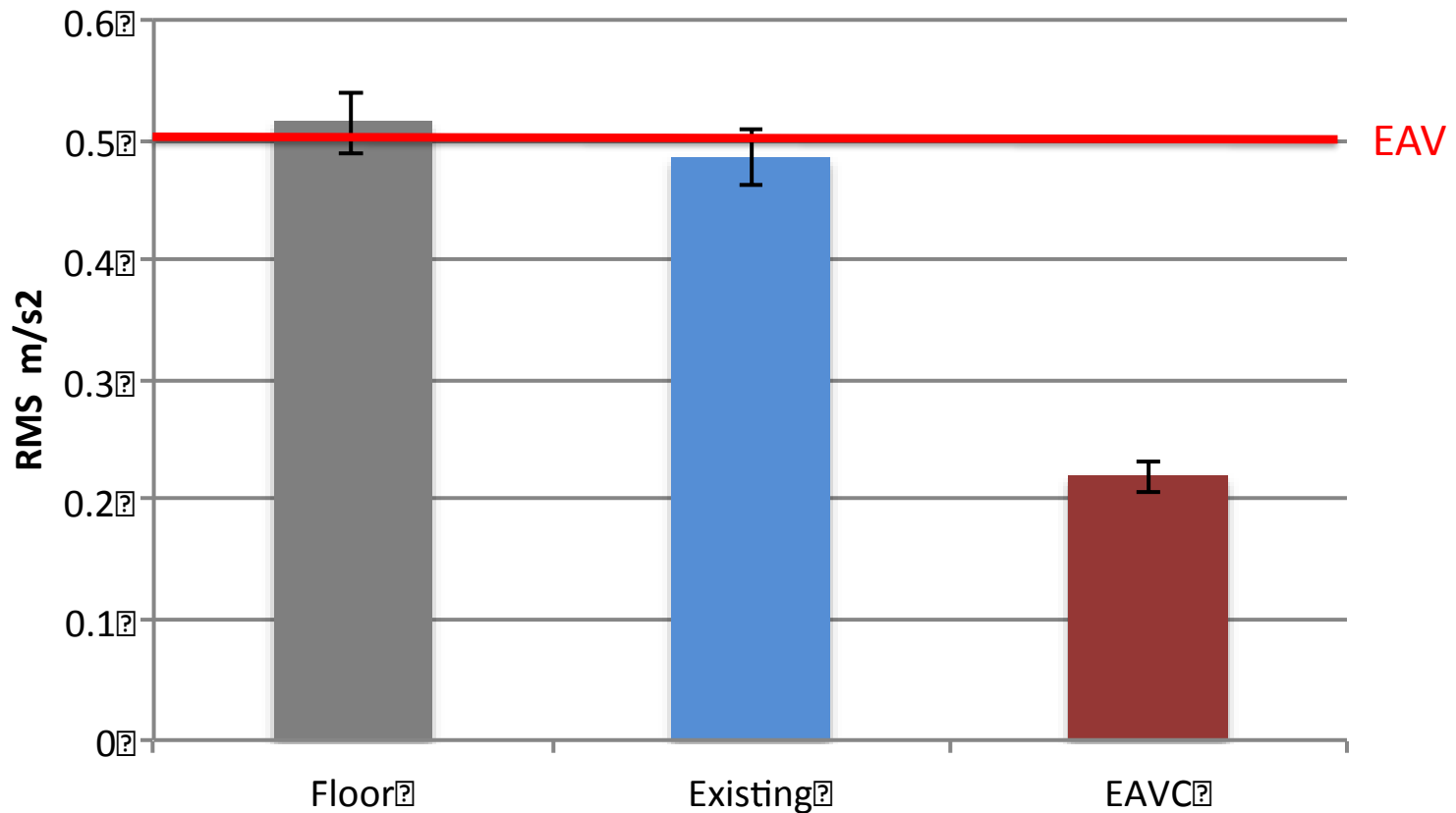


Characteristics of the Workday

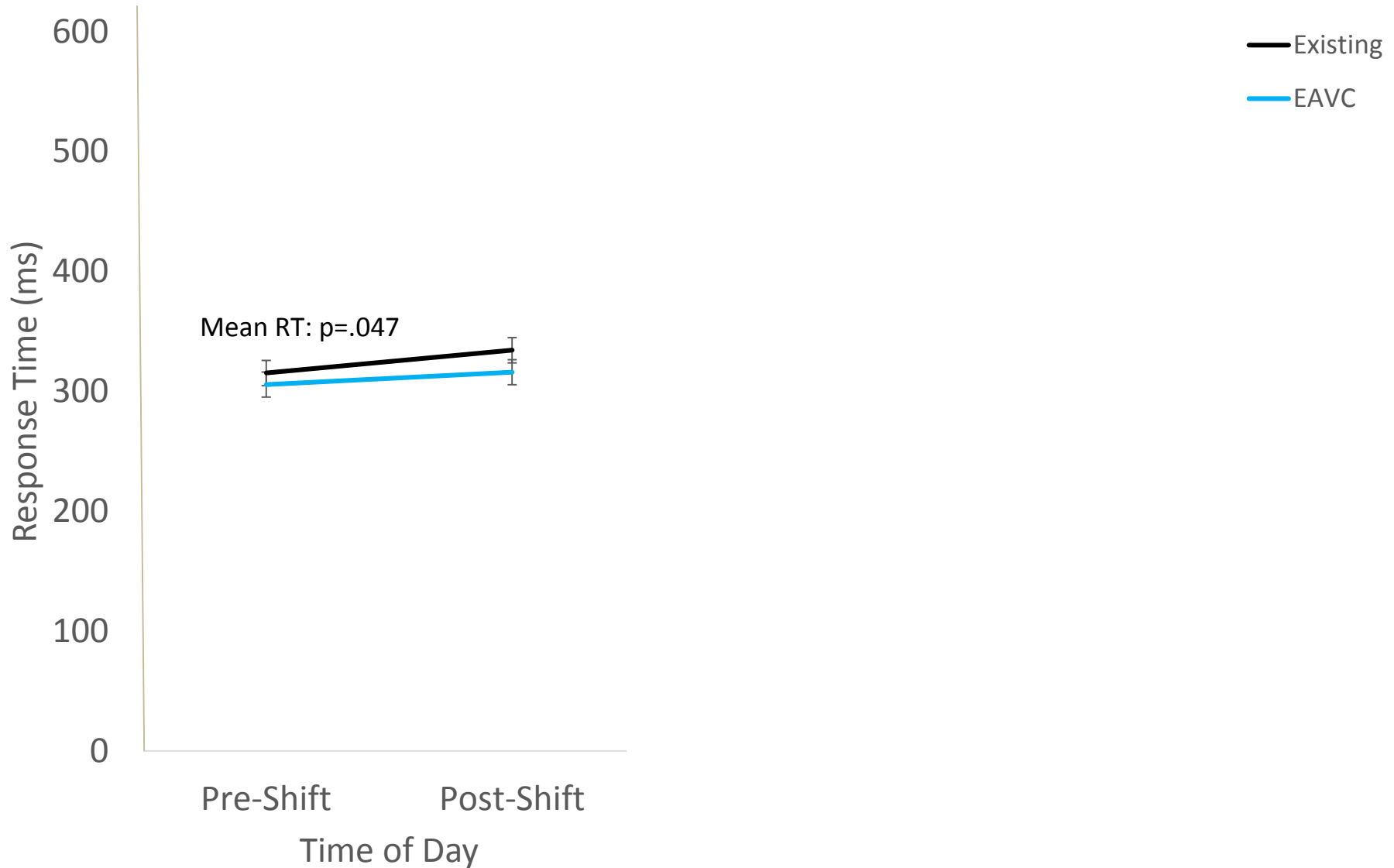
Work Characteristic	Seat Type	Mean	SD	Range
Sleep Duration	Existing	7h 16m	43m	6h 26m - 8h 09m
	EAVC	7h 15m	49m	6h 30m - 8h 16m
Time on Task	Existing	9h 44m	1h 08m	8h 29m – 11h 16m
	EAVC	10h 11m	1h 12m	9h 05m - 12h 10m
Distance (km)	Existing	669	188	341 - 822
	EAVC	662	136	431 - 766
# of Caffeinated Beverages/shift	Existing	1	2	0 - 4
	EAVC	1	2	0 - 4
# of Coffee/shift	Existing	1	2	0 - 4
	EAVC	1	2	0 - 4
# of Energy Drinks/shift	Existing	0	0	0 - 1
	EAVC	0	0	0 - 0
# of Soda/shift	Existing	0	0	0 - 1
	EAVC	0	0	0 - 1
# of Tea/shift	Existing	0	0	0 - 1
	EAVC	0	0	0 - 1



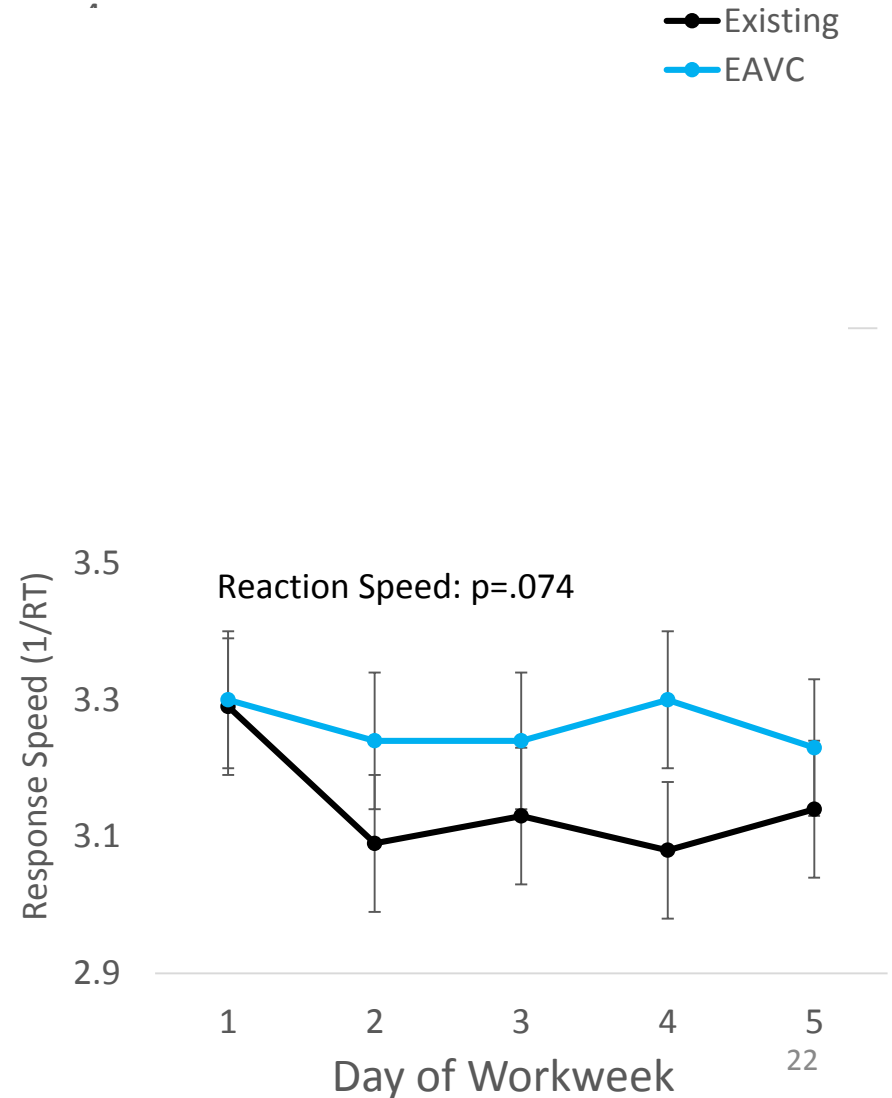
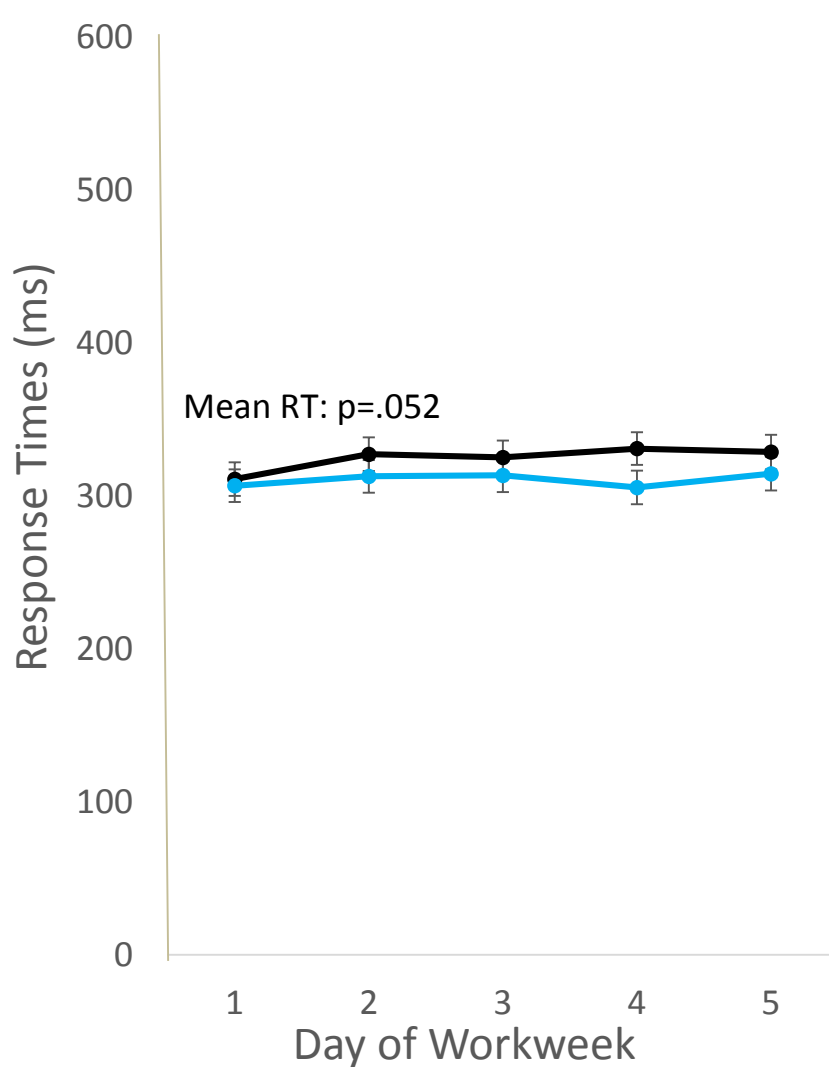
WBV Attenuation



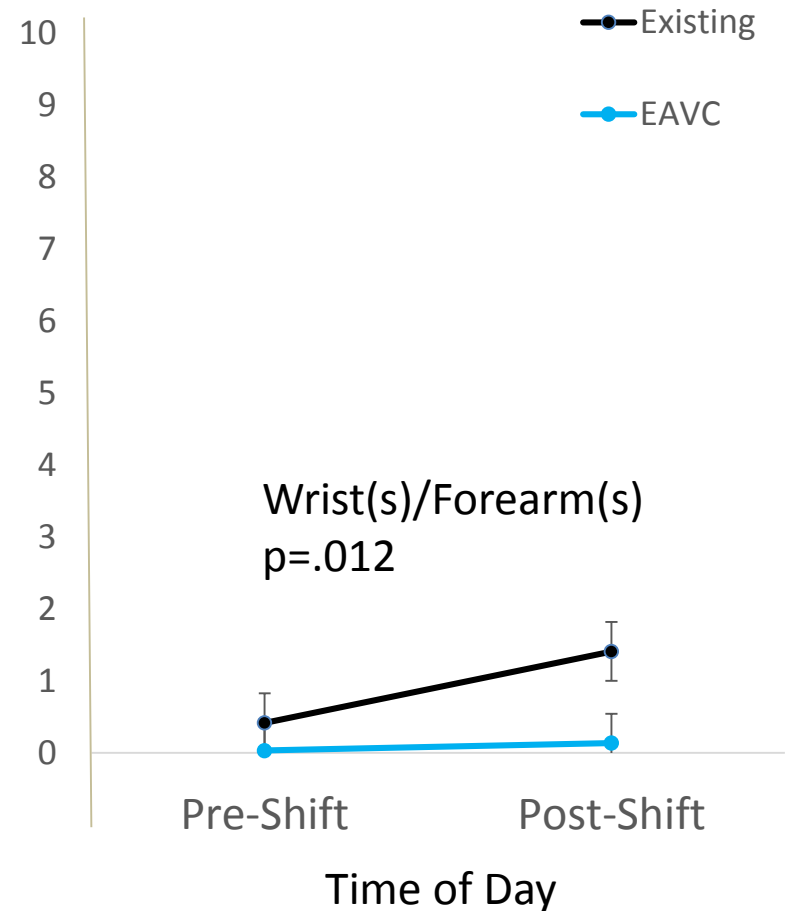
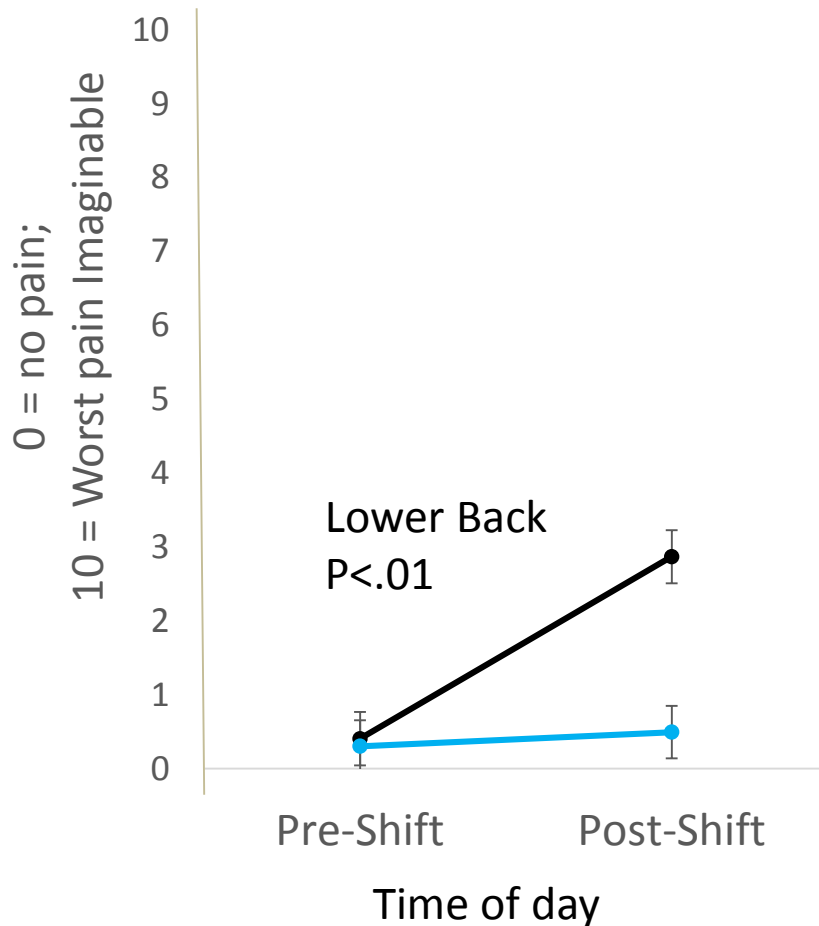
Change in PVT Over Workday



Change in PVT Over Workweek



Change in Discomfort over Workday



Summary

The seating intervention that reduced in WBV →

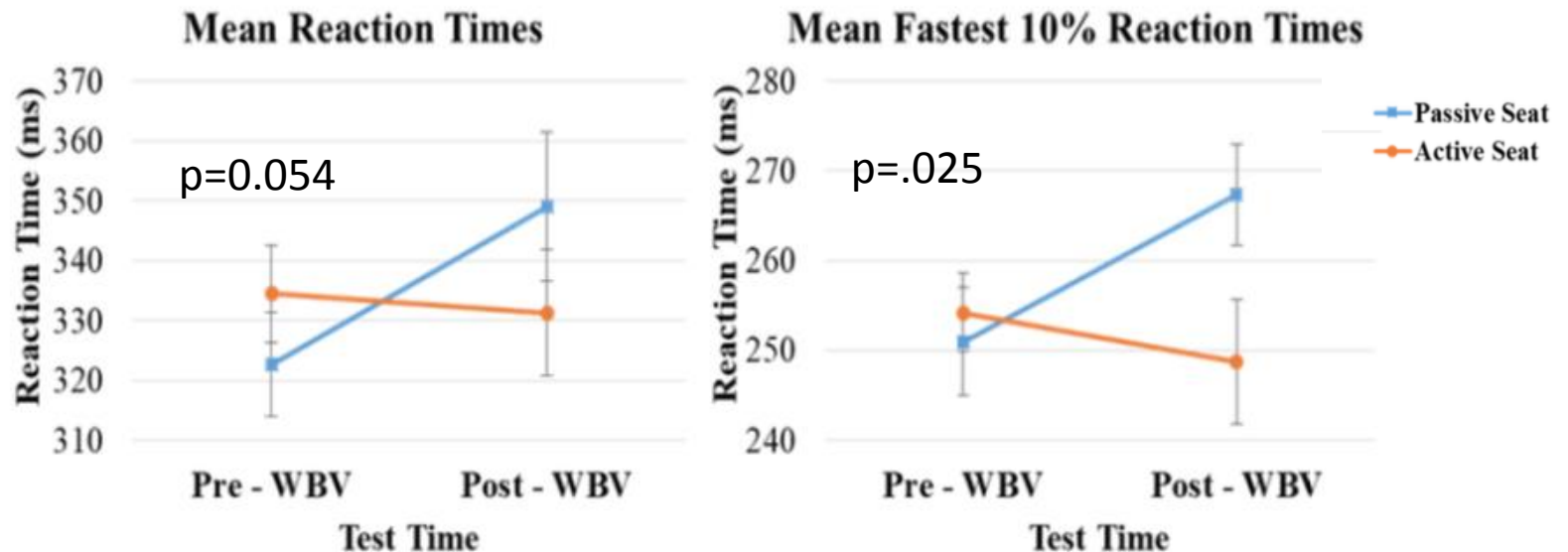
1. Reductions in the decrements PVT performance over a workday
2. Reductions in the decrements of PVT performance over a workweek (trend)
3. Reductions in the development of discomfort in the low back and wrist(s)/forearm(s) over a workday



Replication Study

n=**11 drivers**; **11 hour shifts**; mean age = **52.3**

EVAC = **0.27 m/s²** vs. Passive = **0.54 m/s²**



(Wang et al., 7th American Conference on Human Vibration - 2018)

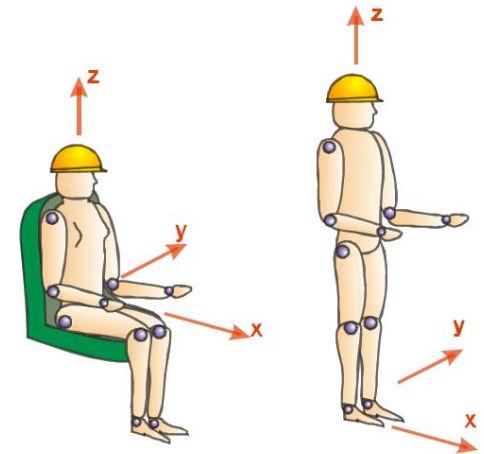
Limitations

- Low sample size
- PVT cannot be assessed while driving
- No randomization or blinding of conditions



WBV Guidelines for (Long-Term) Health and Safety of Workers

- International Guides and Standards
 - **Measurement**
 - **Evaluation**
 - **Assessment**
- British Standard 6841 (1987)
- ISO 2631-1 (1997); ISO 2631-5 (2004)
- European Union Directive 2002/44/EC



WBV Guidelines

- Exposure Action Value (EAV)
 - If EAV exceeded, the *employer shall establish and implement a programme to reduce to a minimum exposure* (8hr reference: $0.5 \text{ ms}^{-2} \text{ r.m.s.}$)
- Exposure Limit Value (ELV)
 - If ELV exceeded, the *employer shall take immediate action to reduce exposure below ELV* (8hr reference: $1.15 \text{ ms}^{-2} \text{ r.m.s.}$)
- Mechanical Shock
 - Transient force, short duration and high amplitude
 - Crest factors > 9 (ratio of highest impact magnitude to weighted r.m.s. - ISO 2631-1).
 - EAV: $9.1 \text{ m/s}^{1.75}$
 - ELV: $21 \text{ m/s}^{1.75}$



WBV Acute Effects and Guidelines?

- No current guidelines for potential acute effects from WBV
- There are several gaps in applying existing knowledge of possible WBV acute effects:
 - Responses from deterministic oscillatory motion
 - Occupationally relevant?
 - Single system/domain effects
 - Few laboratory-controlled experimental studies



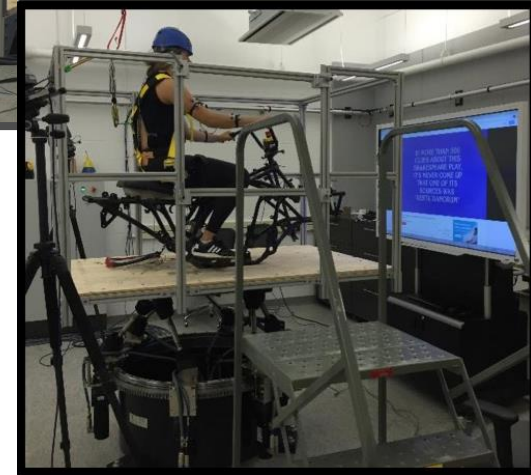
Study Objectives

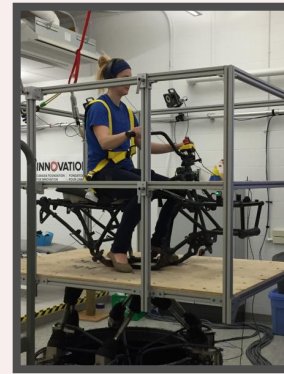
1. Is there an effect of 60-minutes of WBV exposure at four different vibration intensities? (Pre vs. Post)
2. Are there differences in effects between WBV intensities? (Based on EU Directive Guidelines)



Study Methods

- 18 healthy participants (9M; 9F)
 - 26.1 years $\pm$ 5.3; 1.73 meters $\pm$ 0.09; 67.6 kilograms $\pm$ 10.8
- 4 conditions on 4 separate days at least 24 hrs apart, randomized
- Simulated signals based on field data from ATV agricultural herding work
- Vibration intensity standardized to estimated total daily WBV exposure of 2.43 hrs (Clay et al., 2015)
- Participant weight-adjusted





- Quiet Sitting

- *EAV**
- 0.938 m/s^2 RMS
(SD = 0.06)

- EAV + Transient impact
- 10.46 CF
- $13.49 \text{ m/s}^{1.75}$ VDV
(SD = 5.19)

- *ELV**
- 2.129 m/s^2 RMS
(SD = 0.06)

60 minutes exposure

Standardized television programming to mitigate boredom

Noise cancellation headphones

Hands on handlebars, feet on platform surface

5 Hz along Z-axis

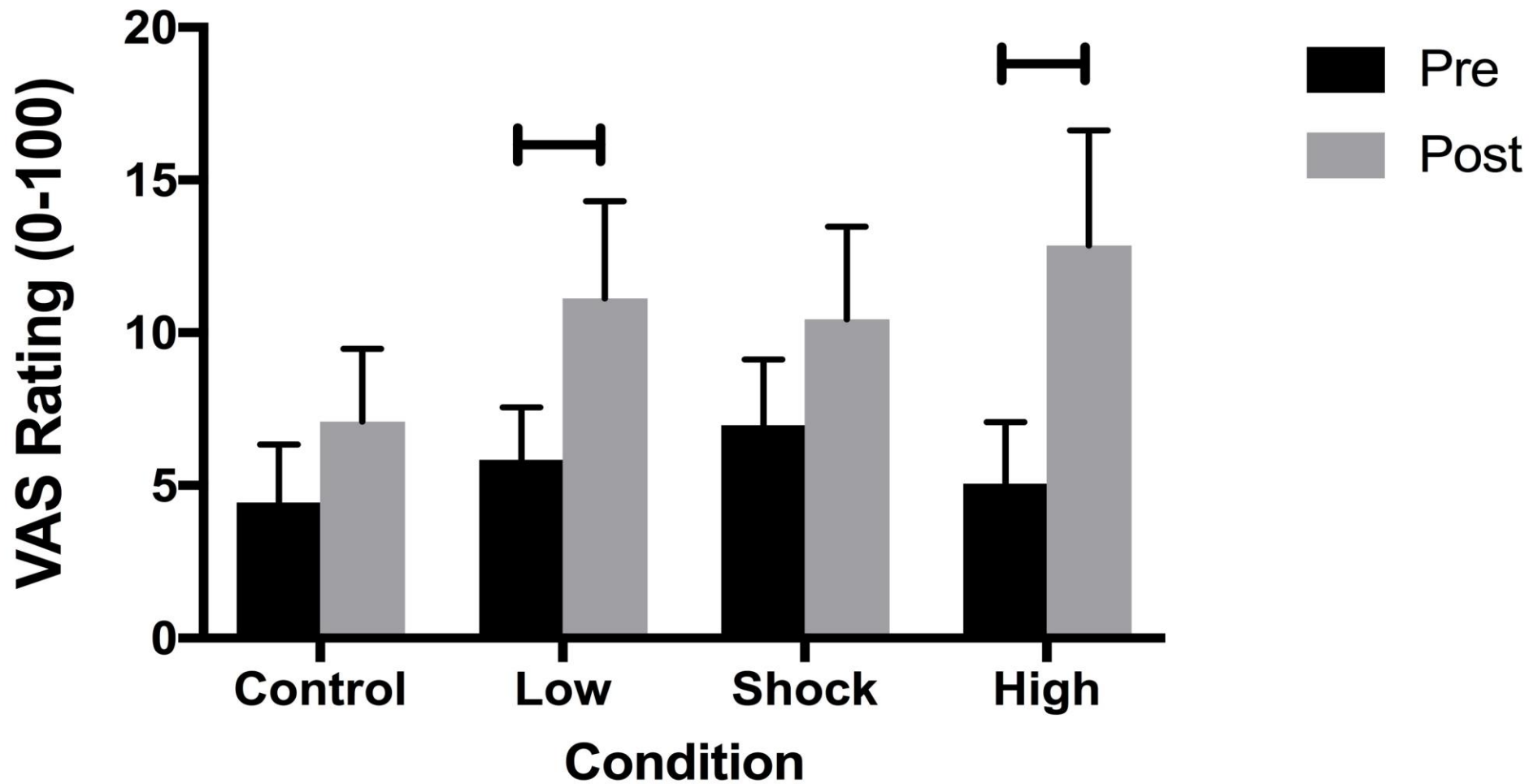


Study Methods - Measurement

- Test battery pre- and post- condition
- Nine cognitive and sensorimotor indices or measures
- Example:
 - **Rating of Perceived Headache/Discomfort (10 cm VAS)**

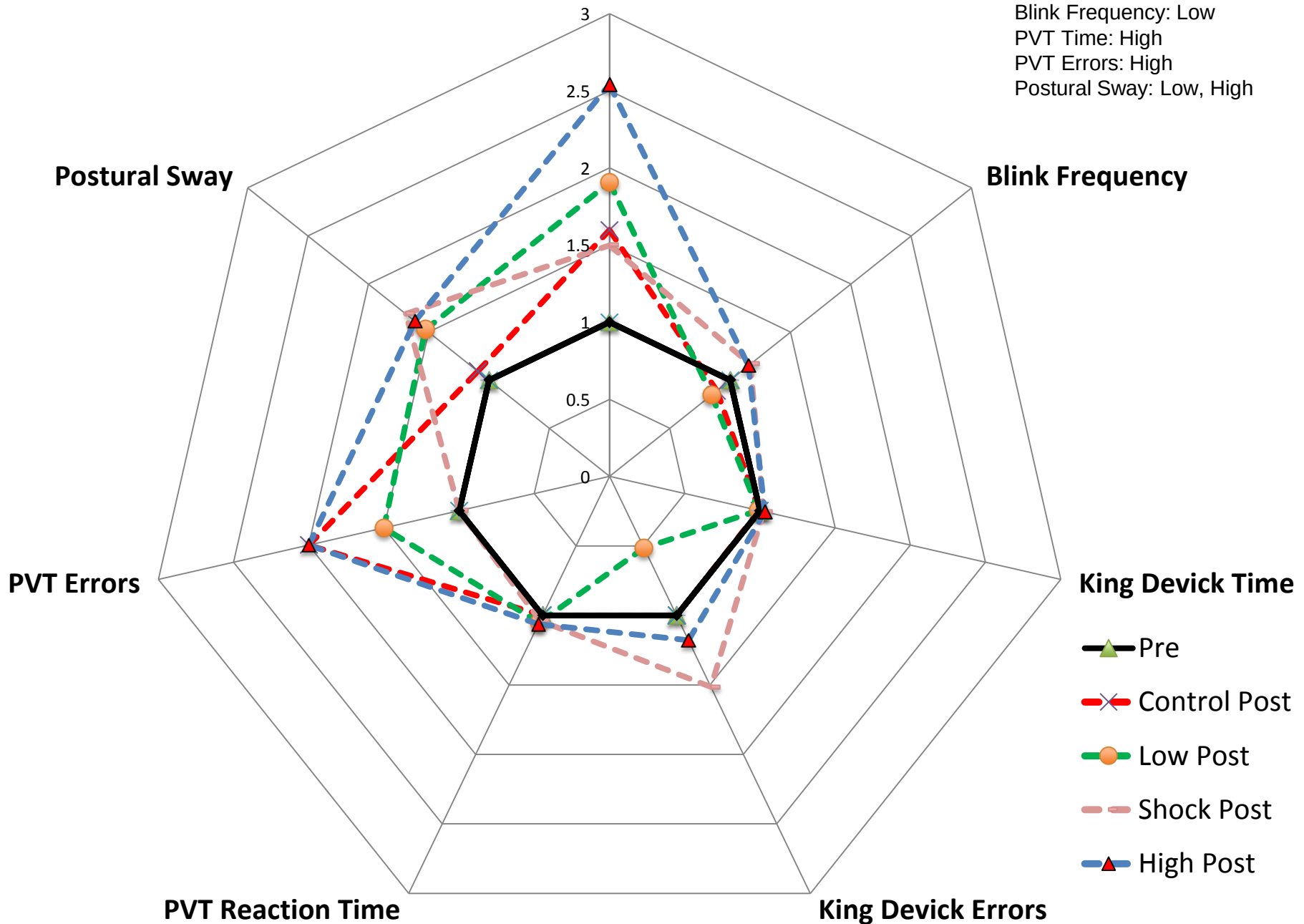


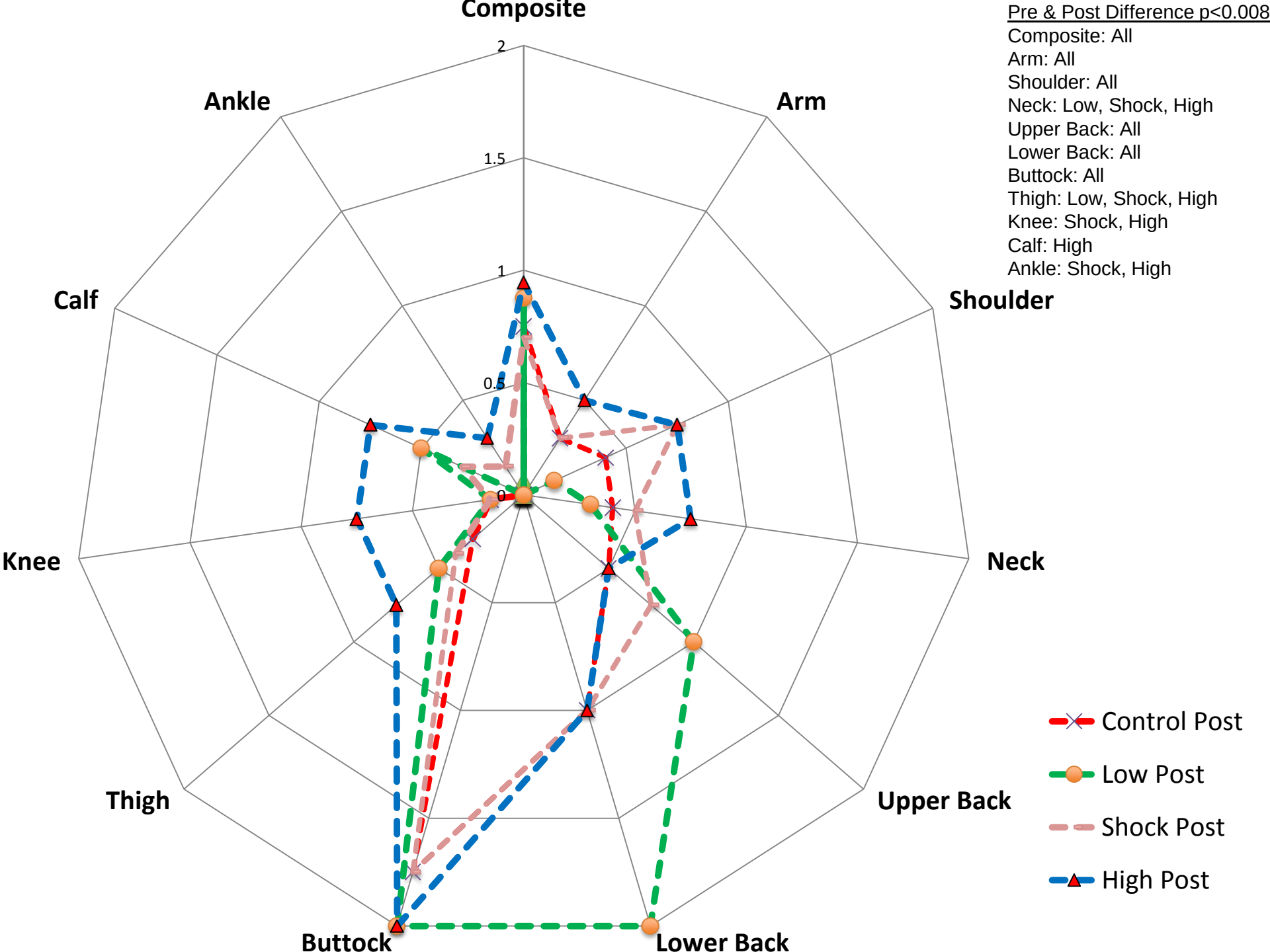
Rating of Headache/Discomfort



Rating of Headache/Discomfort

Pre & Post Difference $p < 0.05$
Headache/Discomfort: Low, High
Blink Frequency: Low
PVT Time: High
PVT Errors: High
Postural Sway: Low, High





Summary

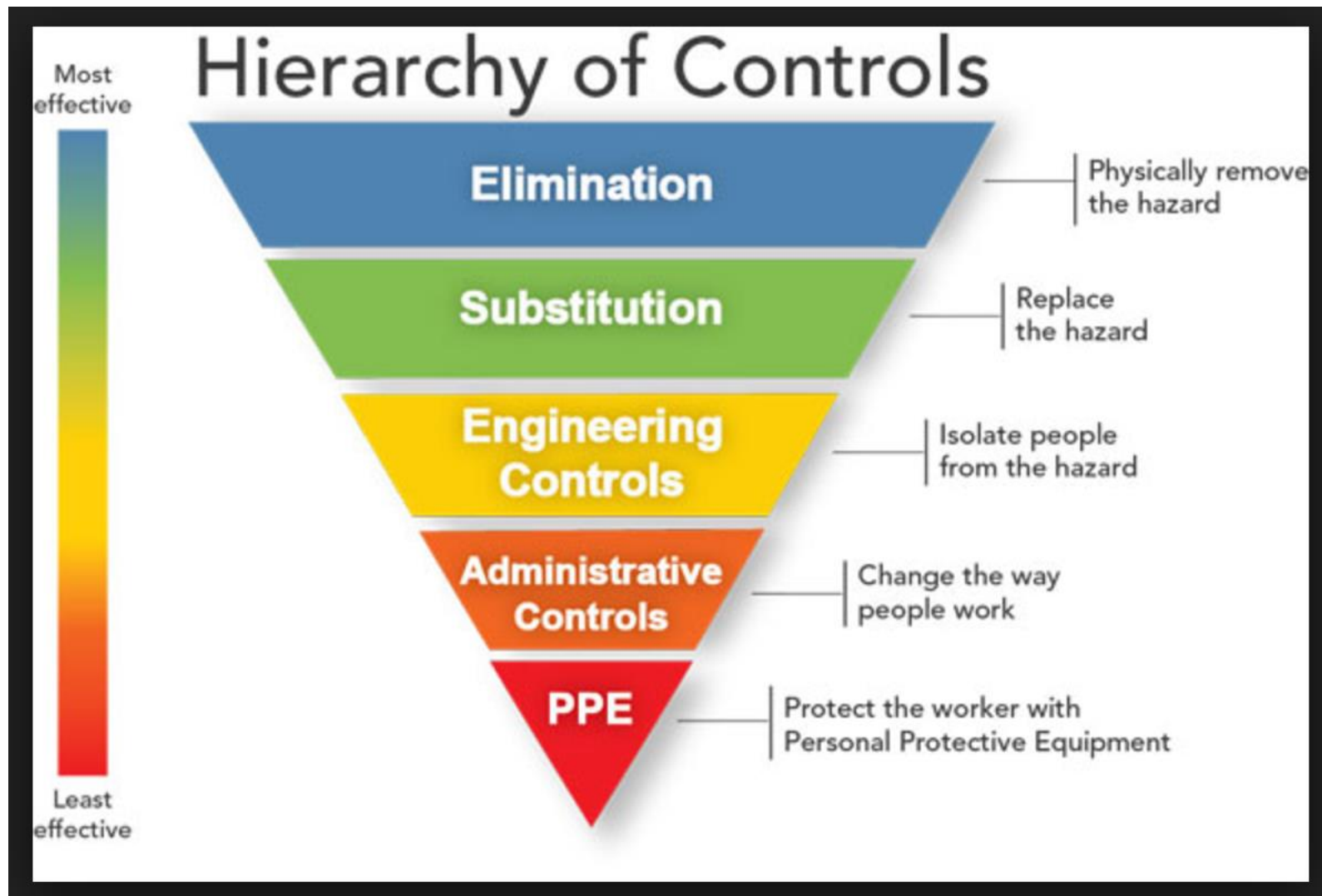
- Control: Upper body discomfort
- Low: Upper body discomfort, Headache/discomfort, postural imbalance, effect on cognitive functioning less clear
- Shock: Whole body discomfort but no significant effects in remaining variables (stiff vs. floppy postural adjustment strategies to sudden perturbation)
- High: Whole body discomfort, Headache/discomfort, postural imbalance, decrements in vigilance.



Summary

- WBV did not induce additional effects beyond those seen for sitting without vibration.
- WBV is not necessarily the only source of acute sensorimotor or cognitive effects.
- However, pre-post effect increased with increasing vibration intensity
- *Quantitative guidance is insufficient to identify vibration hazards but qualitative guidance (i.e., reduce the risk to a minimum) is the key message (Griffin, 2003)*





Risk Mitigation and Interventions

- Active suspension seats are effective
 - But expensive
 - Doesn't address prolonged sitting
- Work-Scheduling/Arrangement
 - Discretionary
 - Non-routine type of work

Day 1		Day 2		Day 3		Day 4		Day 5	
Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
Basements	Basements	Basements	Clean Up, Installation						
Basements	Basements	Basements	Clean Up, Installation	Basement	Clean-up, Above cabinet 3/4" crimping, testing			Basements	Basements
Installation & Finishing	Installation & Finishing	Installation & Finishing		Installation	Basements	Basements	Basements (approx 200 crimps total)	Finishing	
Installation & Finishing	Installation & Finishing	Installation & Finishing	Installation & Finishing	Installation	Basements	Basements	Basements	Finishing (approx 4 homes)	
Basements	Basements	Testing	Basements	Basements	Basements	Basements (approx 100 crimps total)		Basements	Basements
Basements	Basements	Testing	Basements	Basements	Basements	Basements (approx 100 crimps)	Testing, Clean Up	Basements	Basements
Free Standing Bathtub	Free Standing Bathtub	Free Standing Bathtub (Skirting)	Free Standing Bathtub (Skirting, approx 50-60 crimps)	Cut and Rough-In	Drops (approx 40 crimps)	Drops (crimping and hammering)	Drops (approx 60 crimps)	Testing and Risers	Kitchen and Drops
Free Standing Bathtub	Free Standing Bathtub	Free Standing Bathtub	Free Standing Bathtub	Roaming	Finishing	Roaming		Drops	Roaming
Finishing	Finishing (approx 100 crimps)	Bathtubs	Bathtubs	Finishing	Finishing (approx 50 crimps)				
Piping	Piping (approx 200 throughout day)			Finishing	Basements (less than 20 crimps)	Piping	Piping	Water Pipe (copper pipes, 25-90 crimps)	Basements
Rough-In	Rough-In	Bathrooms, Installation, Test	Finishing	Finishing	Installation	Basements (5-6, 3/4" crimps)		Bathtubs	Roaming
Cut Pipes	Drops (20 - 25 crimps)	Lifting tubs, toilets, 3 bathrooms	Stacks, Prepare vent for roofs	Finishing (4 crips per), fetching	Finishing, fetching	Shower Pan	Cut pipes, repairs (2, 1/2" crimps)	Shower Pan, Bathtubs (approx 10 crimps)	Risers
ABS Piping	Rough-In	Two bathtubs, repairs (approx 20 crimps)	Stacks (6 houses)	Bathtubs, Installation	Basements	Rough-In	Basements (10-12 crimps)	Bathtubs (approx 14 crimps)	Rough-In
Rough-In	Rough-In		Bathtub (20 crimps)	Bathtubs	Bathtubs	Cut and Rough-In, Pipes		Rough-In	Rough-In
Rough-In	Rough-In	Installation	Bathtubs	Installation, Bathtub	Carry Bathtubs	Cut and Rough-In, Pipes		Rough-In	Rough-In
Cutting Pipe	Cutting Pipe	Bathtubs	Installation	Bathtubs, Installation	Bathtubs, installation (14 homes)	Cut and Rough-In, Pipes		Risers	Risers

Yung et al., (2014) Detecting within- and between- day manifestations of neuromuscular fatigue at work: an exploratory study. *Ergonomics*, 57(10).

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Publications of Interest:

Yung, M., Tennant, L., Milosavljevic, S., & Trask, C. (2018). "The multi-system effects of simulated whole body vibration on sensorimotor and cognitive performance". *Annals of Work Exposures and Health*, 62(7), 884-898.

Yung, M., Lang, A.E., Stobart, J., Kociolek, A.M., Milosavljevic, S., & Trask, C. (2017). "The combined effects of sequential exposure to whole body vibration and physical, mental, and concurrent work demands. *PlosOne*, 12(12), e0188468.

Du, B. B., Bigelow, P. L., Wells, R. P., Davies, H. W., Hall, P., & Johnson, P. W. (2018). The impact of different seats and whole-body vibration exposures on truck driver vigilance and discomfort. *Ergonomics*, 61(4), 528-537.



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