



Whole-Body Vibration Exposure in the Workplace: Characteristics, Health Risks, Measurement and Control Strategies

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CROSH Webinar

March 29, 2017

12:15 – 1:00 PM

Laurentian University

Sudbury, ON, Canada

Webinar Overview

- Vibration Basics
- Health Risks
- WBV Measurement & Exposure Characteristics
- Prevention and Reduction Strategies
- Questions

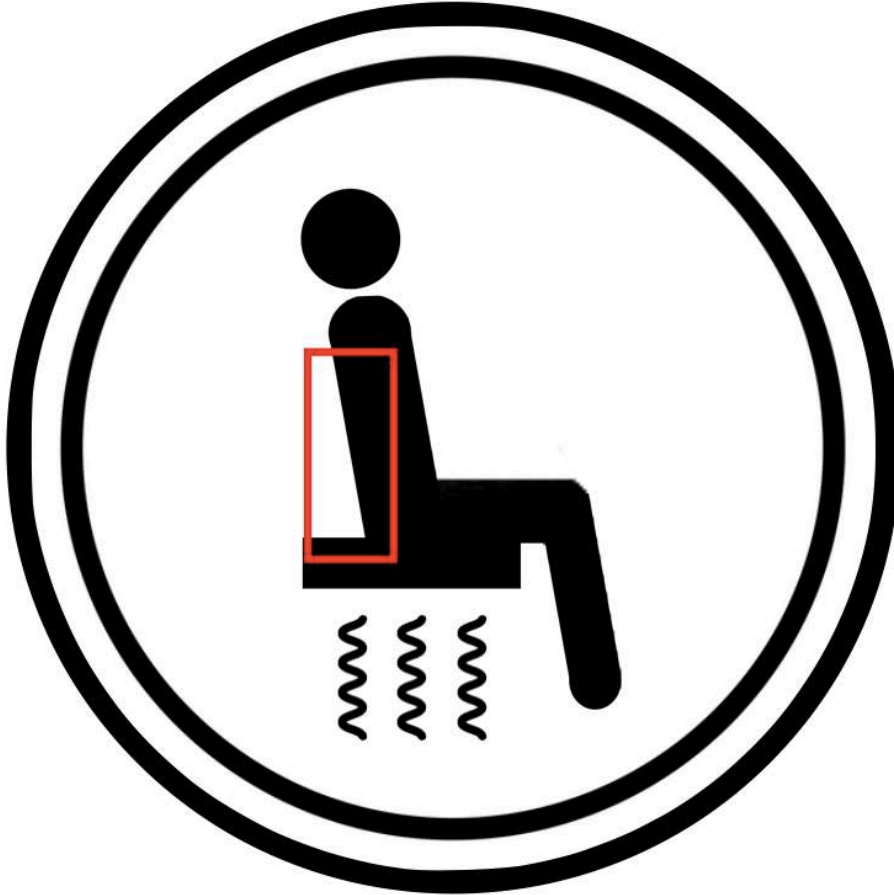


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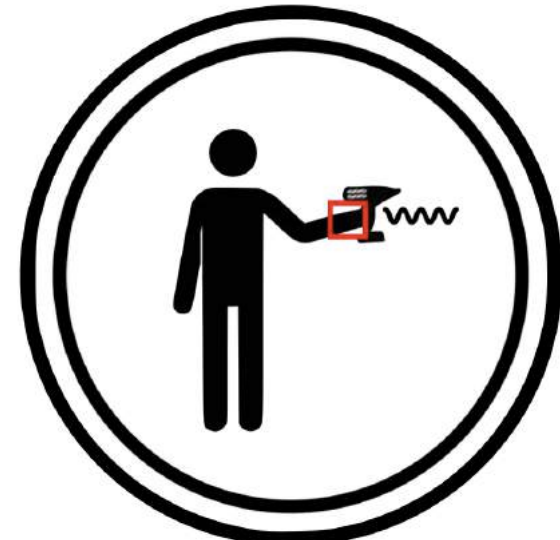
Vibration Basics



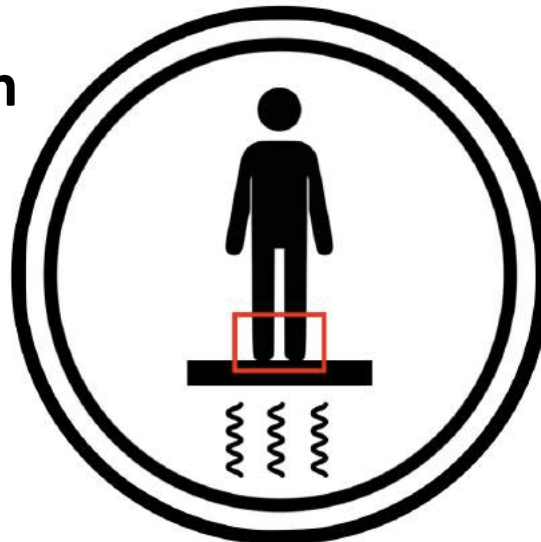
Types of Vibration Exposure



Whole-Body Vibration
WBV



Hand-Arm Vibration
HAV



Foot Transmitted Vibration
FTV

Understanding Human Response

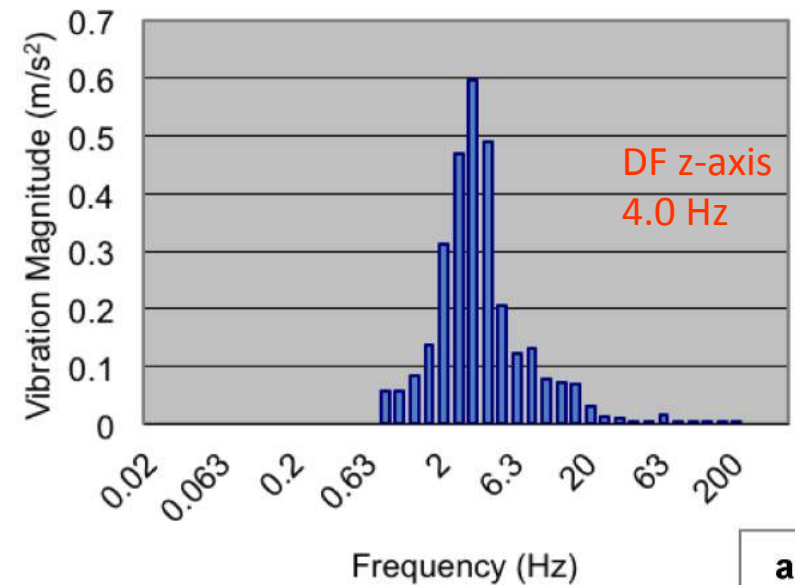
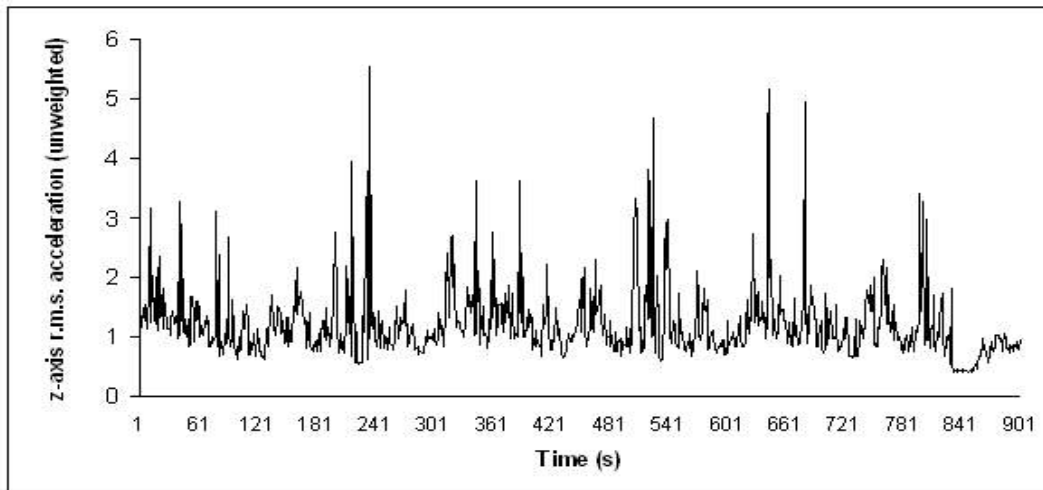
4 factors are required to describe human response to vibration:

1. Magnitude

- 'bounce height' (m/s^2)

2. Frequency

- # of 'bounces' per sec. (Hz)



Understanding Human Response

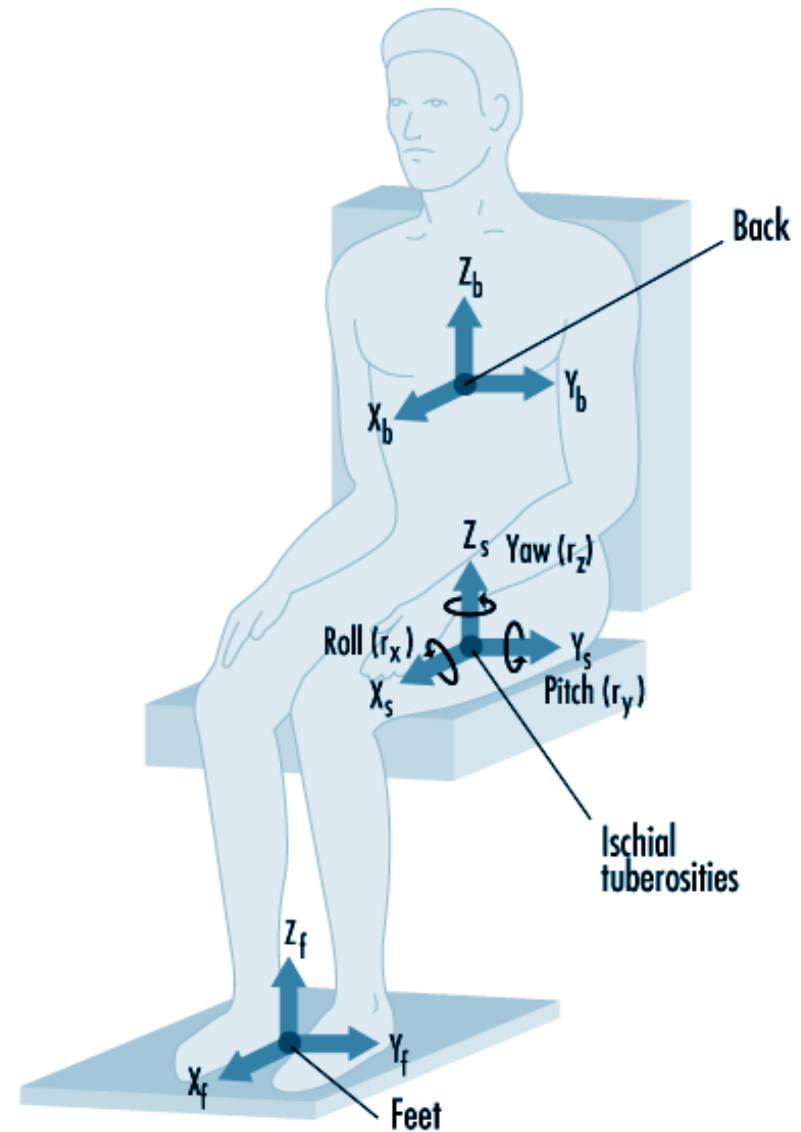
4 factors are required to describe human response to vibration:

3. Direction

- X, Y, Z axes

4. Duration

- length of exposure time



Human Response to Vibration

- Each region of the body has a **natural frequency (resonance)**
- Exposure at resonance is linked with increase injury risk

Pelvis/spine: 3-5 Hz; 10-12 Hz

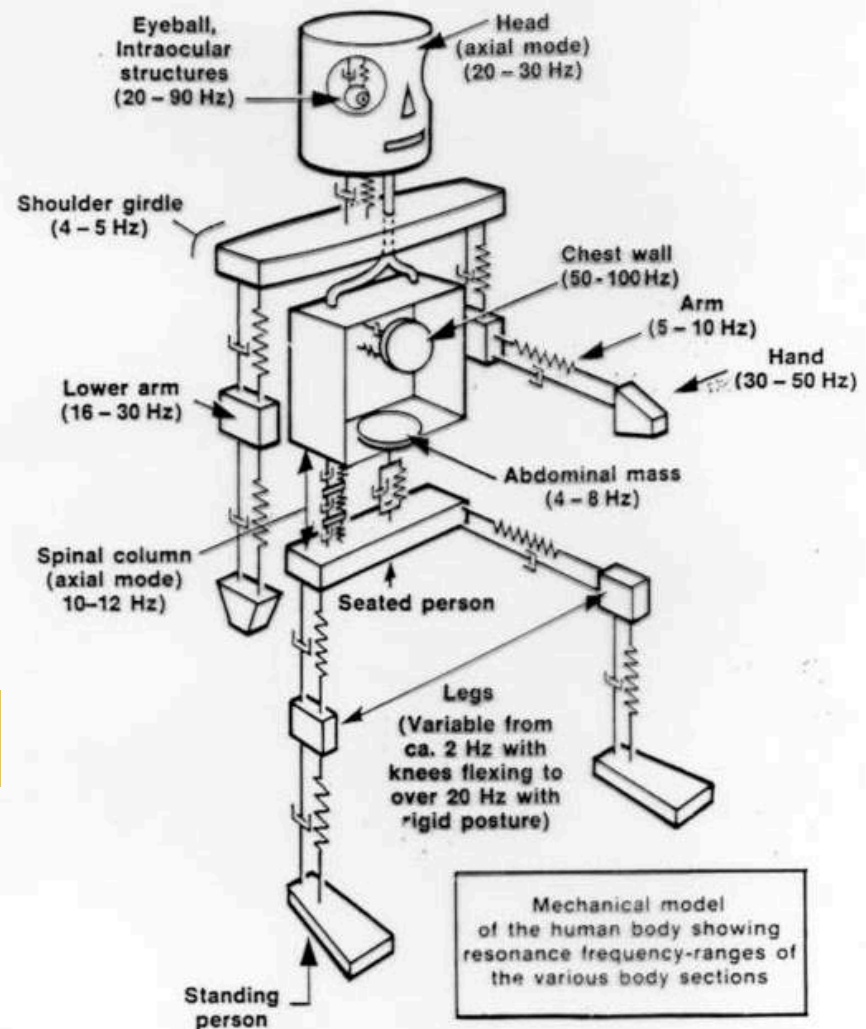


Image From: <http://physics.stackexchange.com/questions/>

Occupational Exposure to WBV

Industry	Vibration Sources
Construction	Earth moving equipment, scrapers, haul vehicles
Forestry/Lumber	Tractor, skidder operations
Mining	Scrapers, bulldozers, loaders, excavators
Transportation	Bus, locomotive, subway, taxi, truck, helicopter
Steel Workers	Crane, foundry shakeouts, stamping sheet iron, drop forging
Concrete	Operations on vibrating platforms, concrete finishing
Manufacturing	Forklift operations on uneven surfaces, textile weaving
Agriculture	Tractor driving, harvesting

http://www.irsst.qc.ca/media/documents/divers/animation-scientifique-evaluation-reduction-risque-vibratoire/WBV_ACGIH.pdf



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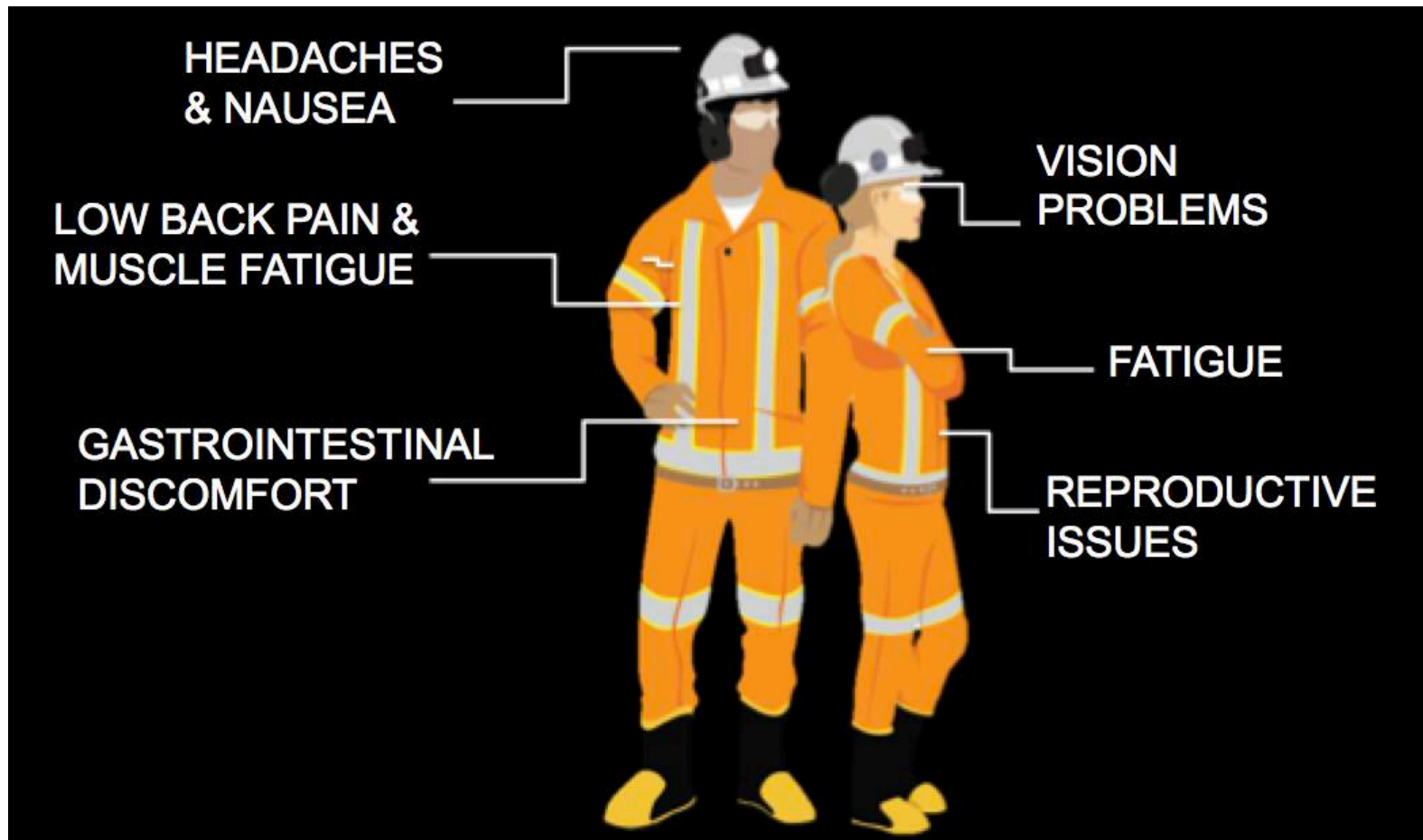
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Health Risks



WBV Exposure and Health Risks



Increased low-back injury risk when WBV exposure is combined with non-neutral postures

Port workers – cranes & lift trucks (Bovenzi et al., 2002)

Farm workers – tractors (Wikstrom, 1993; Bovenzi & Betta, 1994)

Construction – excavators, pavers etc. (Kittusamy and Buchholz, 2004)

Locomotive operators (Johanning et al., 2002)

LHD operators (Eger et al., 2009)



WBV Measurement and Exposure



OHS Legislation

No occupational health and safety regulations specifically related to vibration exposure in Ontario

– General Duty Clause

- 25.(2)(h) every reasonable precaution.. “take every precaution reasonable in the circumstances for the protection of a worker.”

Whole-Body Vibration Measurement

Standards and Guidelines

ISO 2631-1 (1997): *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration -- Part 1: General requirements*

ACGIH: *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*

EU Directive 2002/44/EC

ISO 2631-5 *Method for evaluation of vibration containing multiple shocks*

WBV Measurement

1. Follow ISO 2631-1 guidelines
2. Secure the seat-pad and tri-axial accelerometer on the seat
3. Record vibration for a sufficient duration to be representative of the vibration exposure
4. Instruct the operator to drive the vehicle following regular operating procedures

Example Measurement Equipment



Data-logger



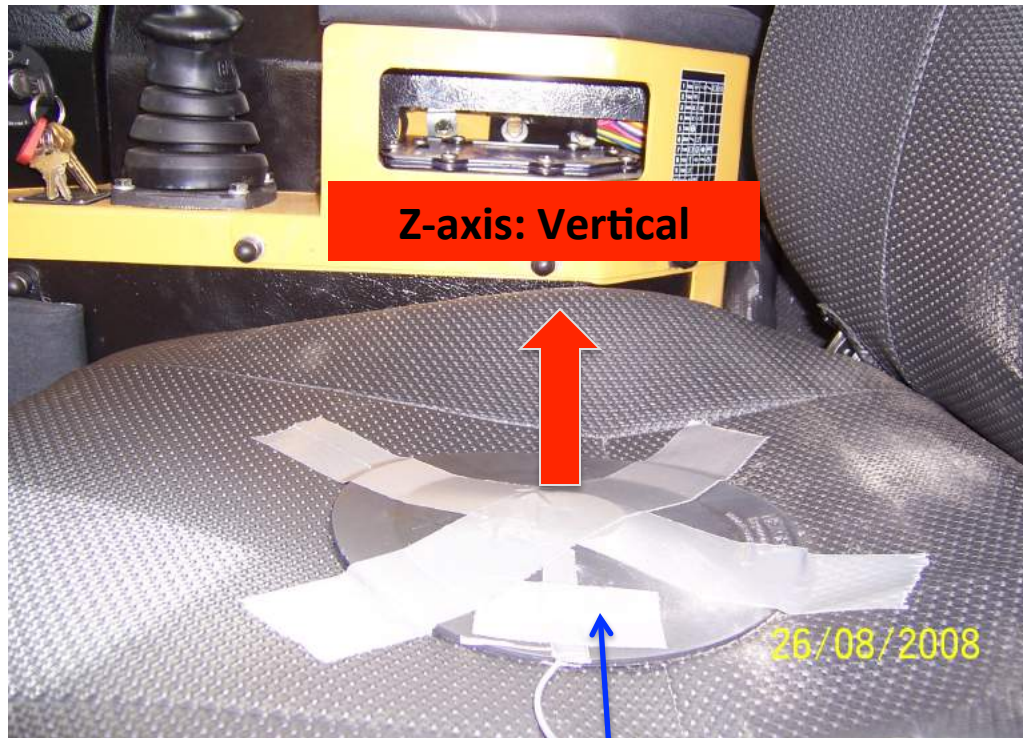
Seat pad



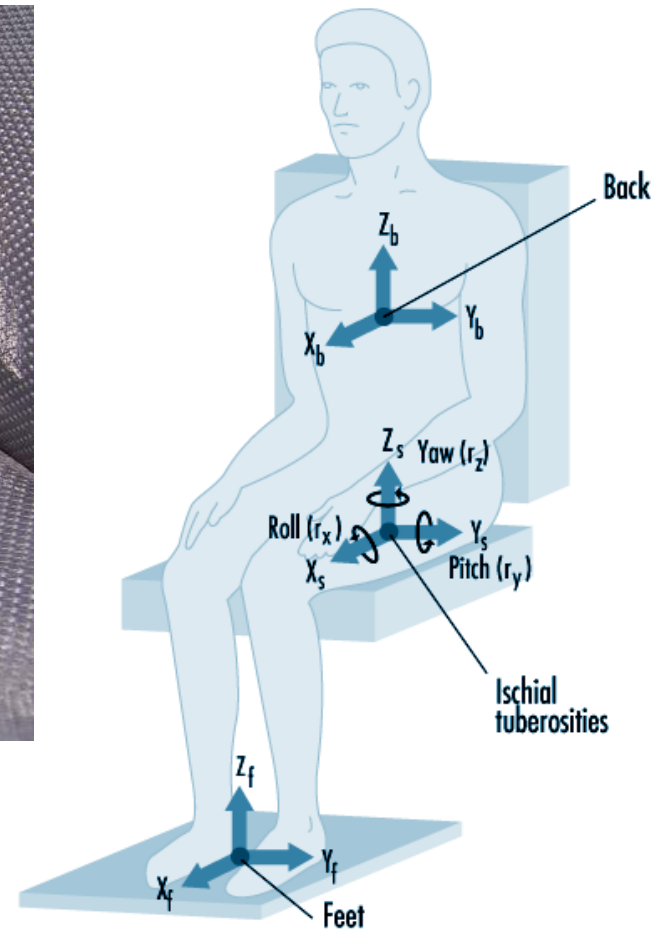
Tri-axial accelerometer



Placement of the Seat-pad Accelerometer

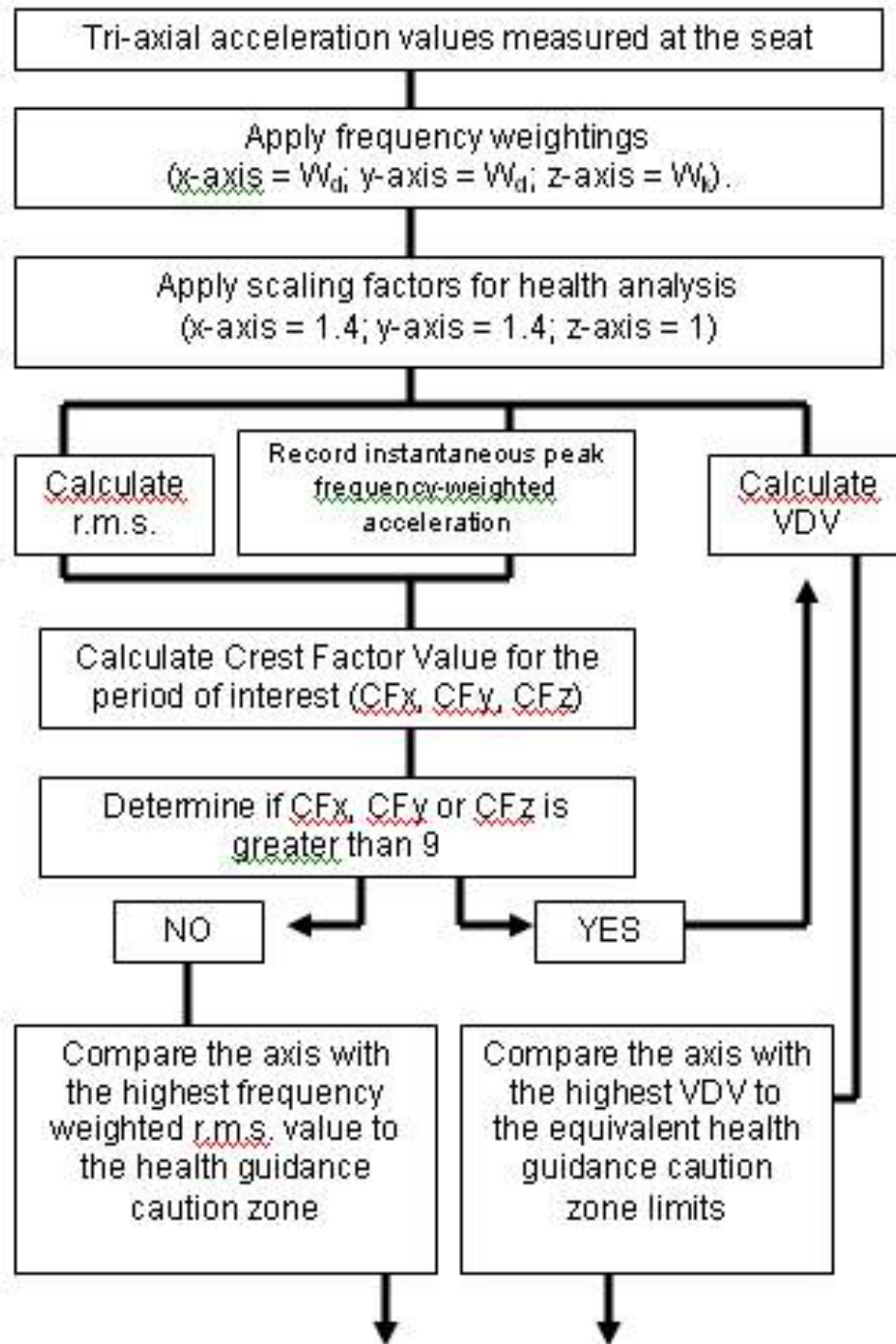


Seat pad



From: http://www.ilo.org/safework_bookshelf/english?content&nd=857170580

ISO 2631-1



Health Risk Determination

Compare the axis with the highest frequency weighted r.m.s. value to the health guidance caution zone

Compare the axis with the highest VDV to the equivalent health guidance caution zone limits

"For exposures below the zone (HGCZ), health effects have not been clearly documented and/or objectively observed"

"..in the zone (HGCZ), caution with respect to potential health risks is indicated"

"..above the zone (HGCZ) health risks are likely"

"Probable" Health Risk	ISO 2631-1	
	A(8) (m/s ²)	VDV _{total} (m/s ^{1.75})
Low	< 0.5	< 8.5
Moderate	0.5 - 0.90	8.5 - 17
High	> 0.9	> 17

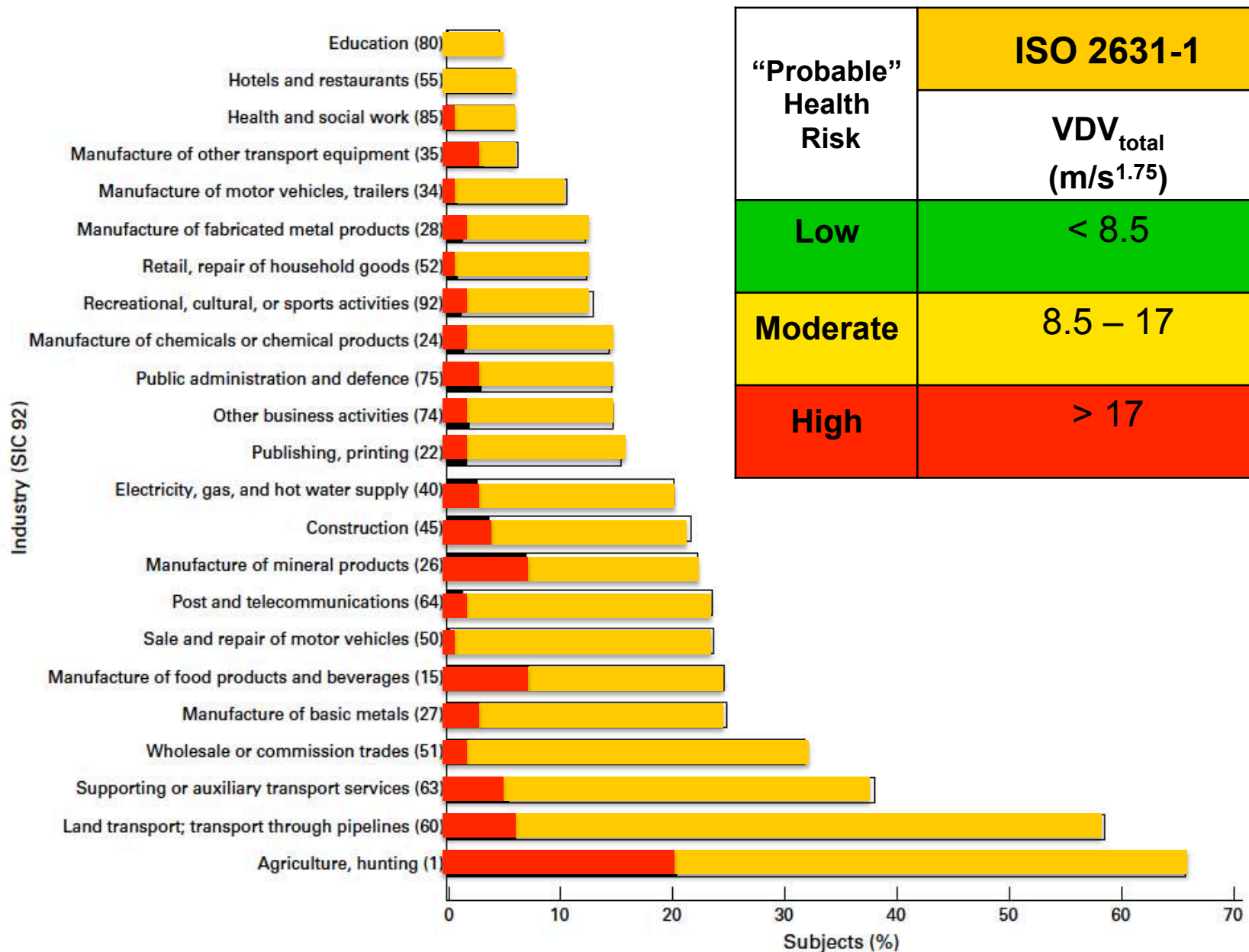
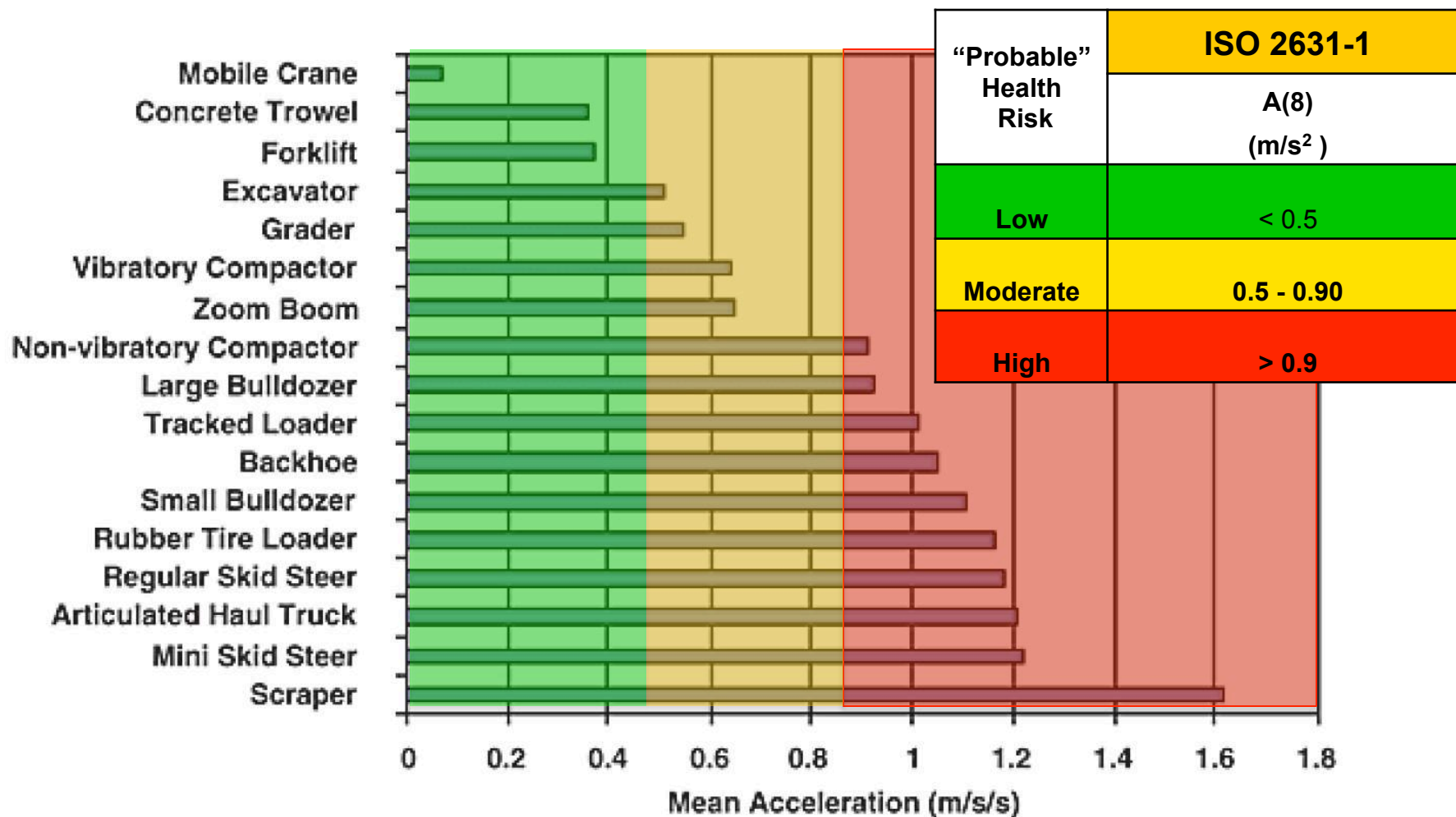


Figure 3 Industries in which significant exposures to whole body vibration most commonly arose in the past week among employed men.

WBV Exposure: Construction Equipment



Example: WBV Exposure Evaluation: LHD Vehicle (Underground Mining)

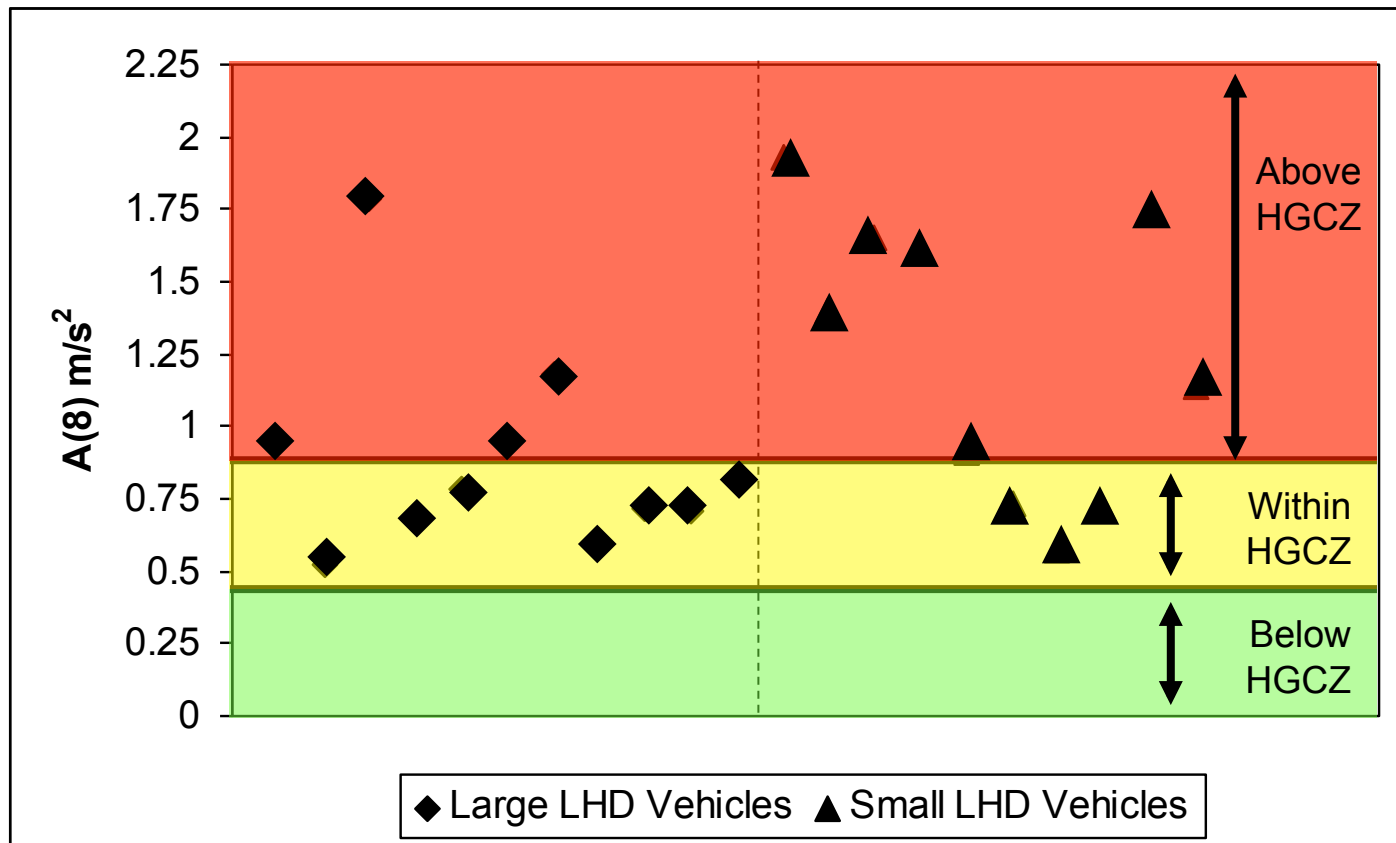
Health risk predictions based on ISO 2631-1 HGCZ comparison



4 of 11 (large) LHD operators were exposed the WBV levels above the HGCZ

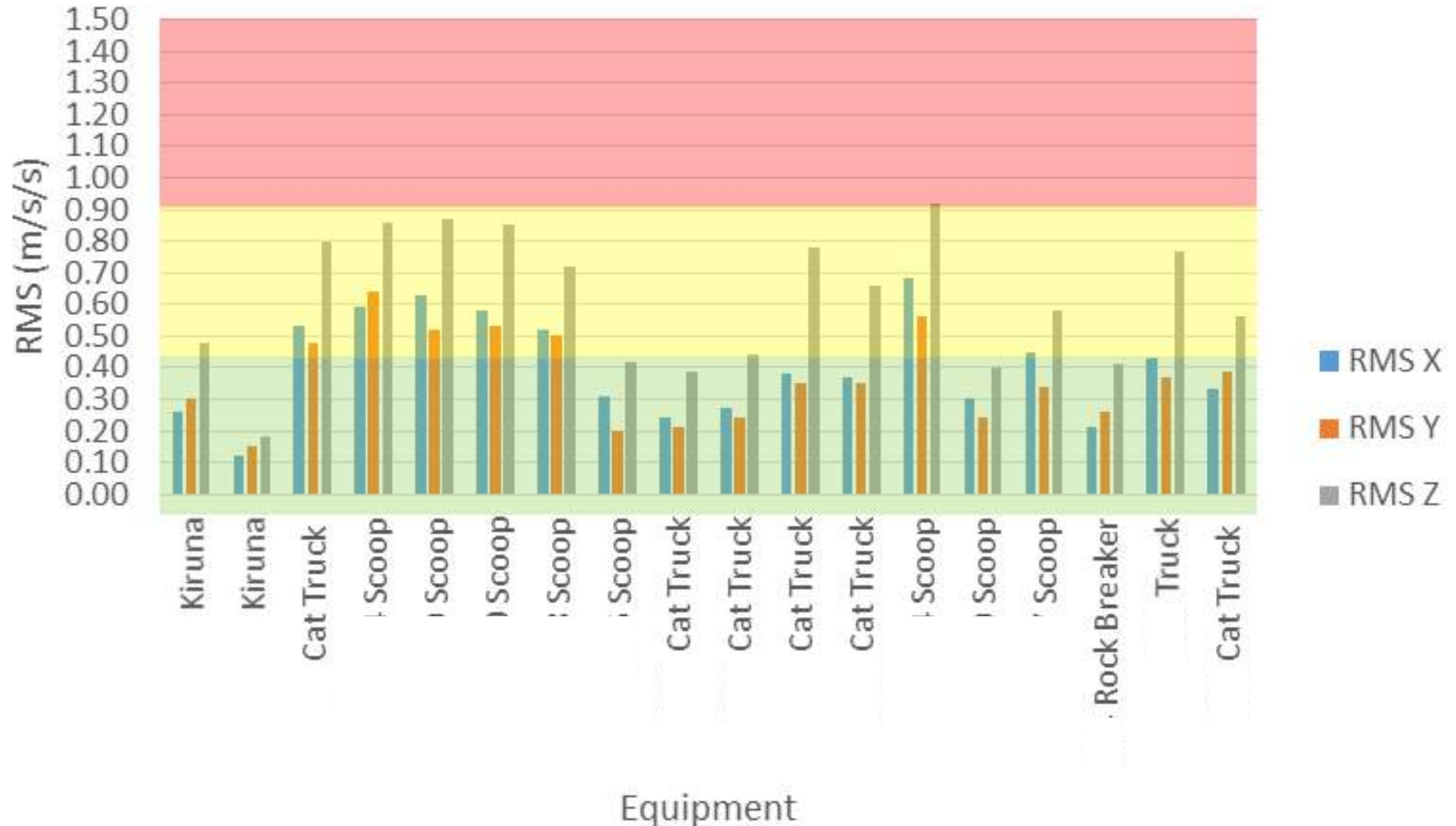
7 of 10 (small) LHD operators were exposed the WBV levels above the HGCZ

(Eger et al., 2013)



Underground Nickel Mine

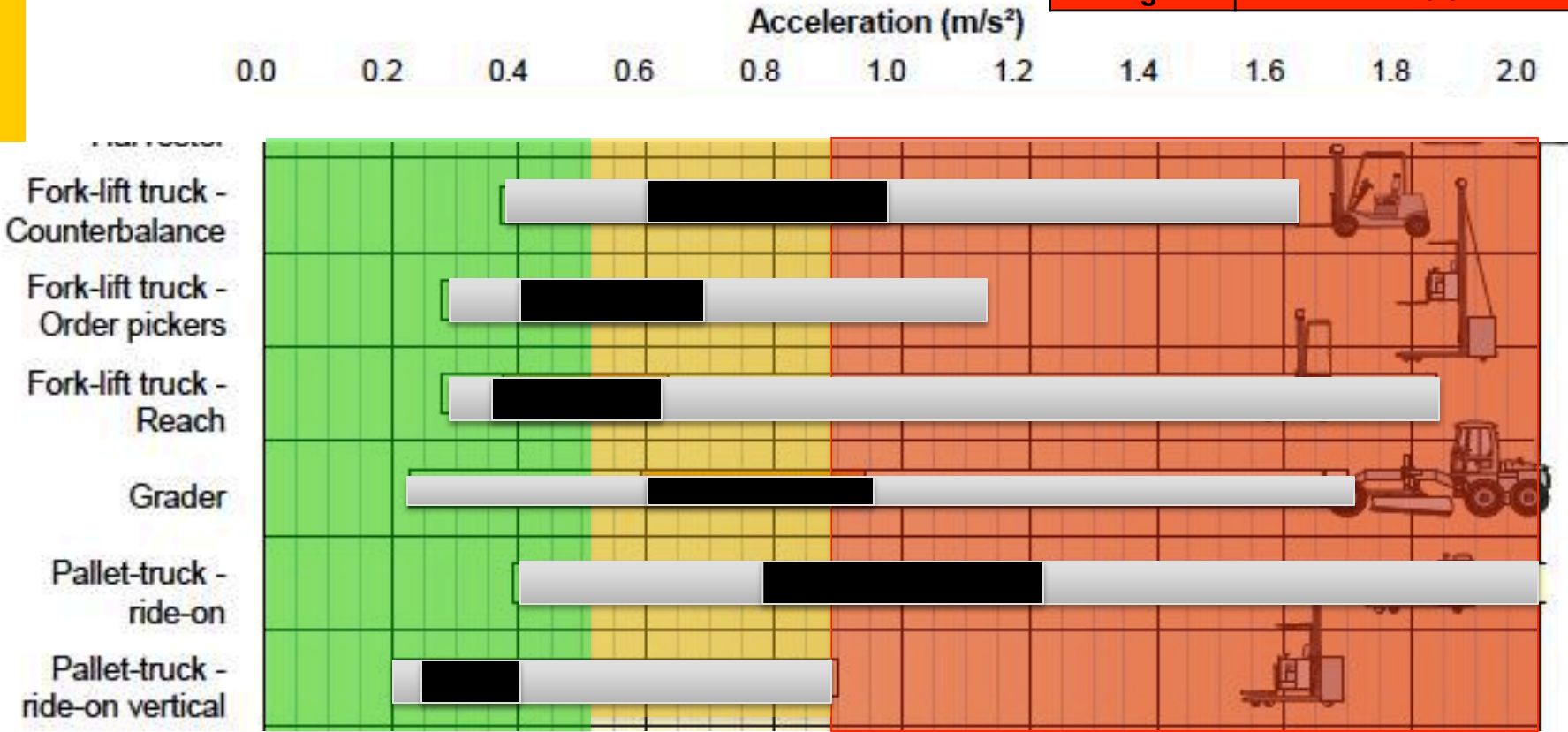
Samples collected with a iPod and WBV app over a 3-week Period



(Killen et al., submitted for publication)

WBV Exposure: Lift-truck Operation

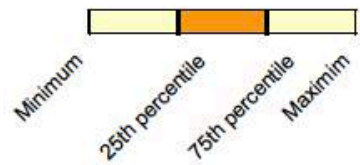
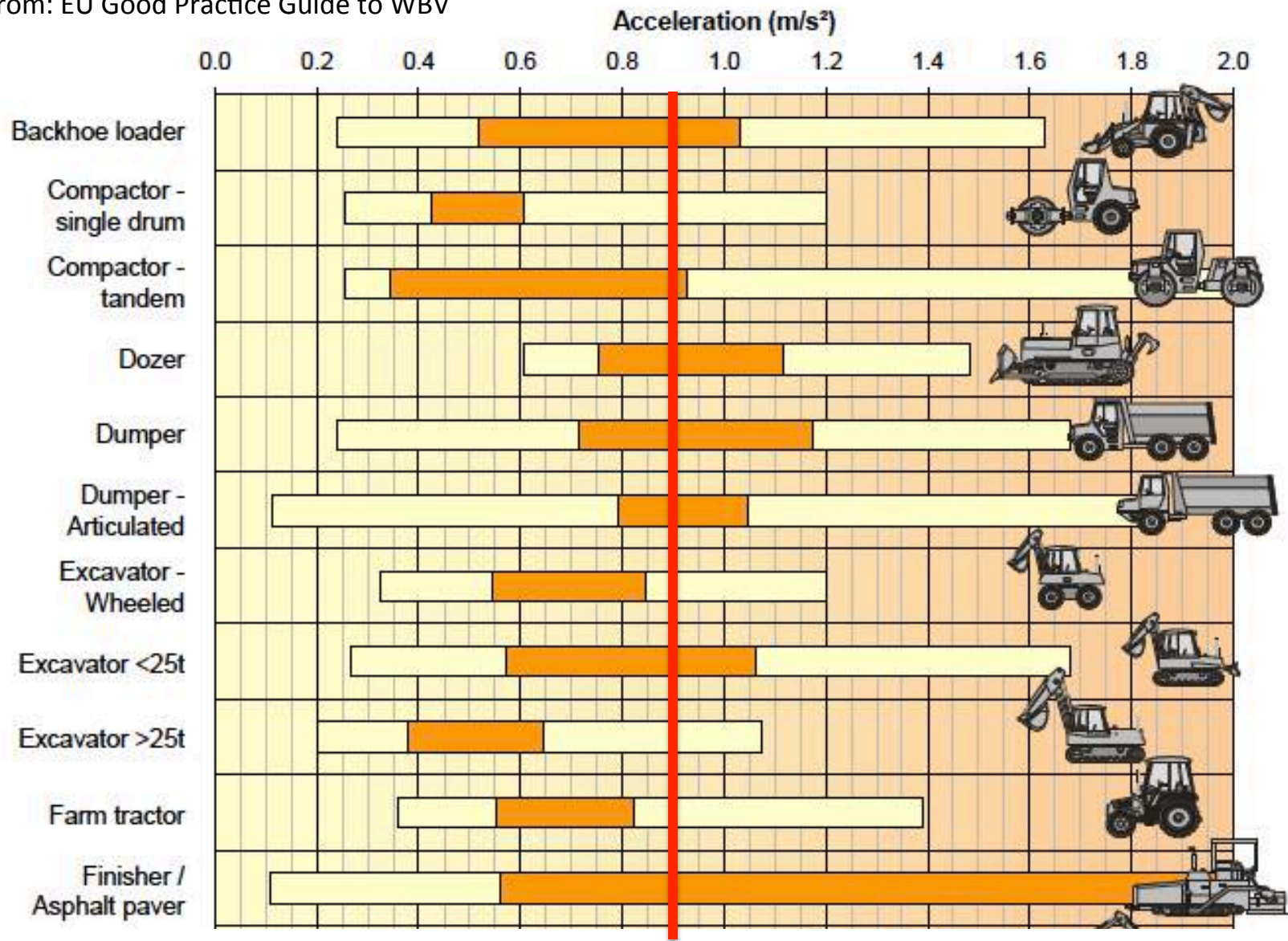
"Probable" Health Risk	ISO 2631-1
	A(8) (m/s ²)
Low	< 0.5
Moderate	0.5 - 0.90
High	> 0.9



Adapted From: EU Good Practice Guide to WBV

http://resource.isvr.soton.ac.uk/HRV/VIBGUIDE/2008_11_08%20WBV_Good_practice_Guide%20v6.7h%20English.pdf

From: EU Good Practice Guide to WBV

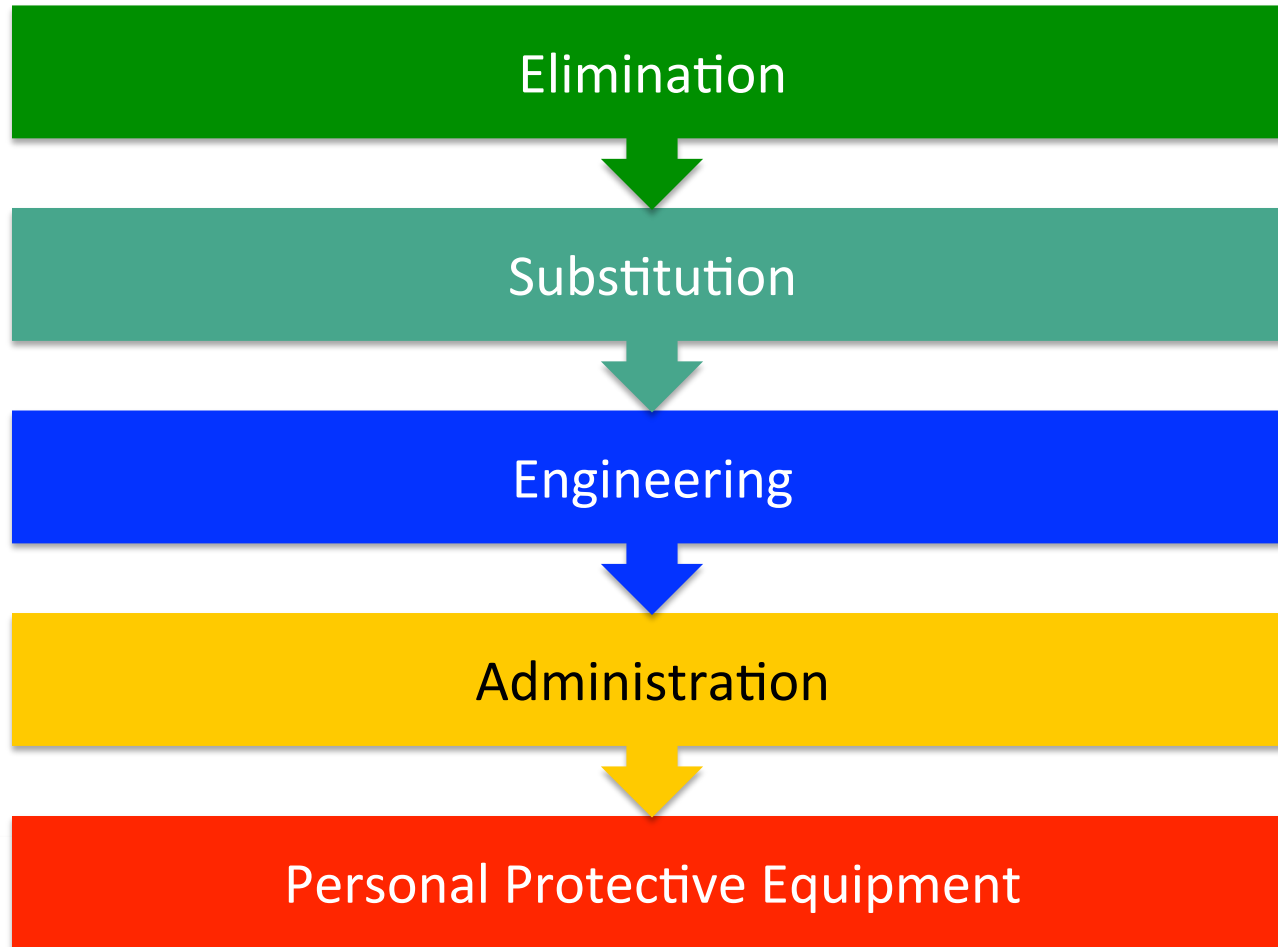


Upper Boundary of the HGCZ

Prevention and Reduction Strategies



Hierarchy of Controls



Controls: Whole-body Vibration

- Remove the worker from vibration source
- Purchase equipment with lower vibration emissions
- Maintain equipment (and roadways)
- Reduce driving speed
- Install suspension and seating suited to the conditions
- Maintain a neutral driving posture
- Monitor exposure to WBV as part of a WBV exposure management plan

Purchasing

- **Purchase equipment with lower vibration emissions**
 - Enquire with the manufacture about WBV exposure values
 - Consider features associated with lower vibration exposure

Example: Ride Control

R1700G

Underground Mining Loader

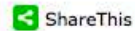


Optional Ride Control

The optional ride control system uses a nitrogen filled oil accumulator in the hydraulic lift circuit to act as a shock absorber for the bucket and lift arms. The lift arm and bucket response to movement is dampened over rough ground, reducing fore and aft pitch, improving cycle times and load retention. A smoother, more comfortable ride gives operators the confidence to travel at higher speeds during load and carry operations.

Example: Ergonomic Design to Reduce WBV Exposure

INTERNAL COMBUSTION CUSHION TIRE LIFT TRUCKS



The industry's first 4-way suspension seat, easy-to-use controls, and low noise and vibration levels enhance operator comfort. Thru-mast visibility reduces fatigue - improving safety and productivity.



<http://www.toyotaforklift.ca/news/detail.aspx?id=164>



1. The rotating cab turns 290 deg., providing a 360-deg. view of the boom and grapple for safer, easier log loading.
2. The innovative auto-leveling cab keeps the operator balanced and comfortable, no matter how steep or uneven the terrain.
3. The fully adjustable air-cushioned seat provides exceptional daylong comfort in the climate-controlled cab.
4. With a wider door-opening angle, getting in and out of a John Deere forwarer has never been easier.

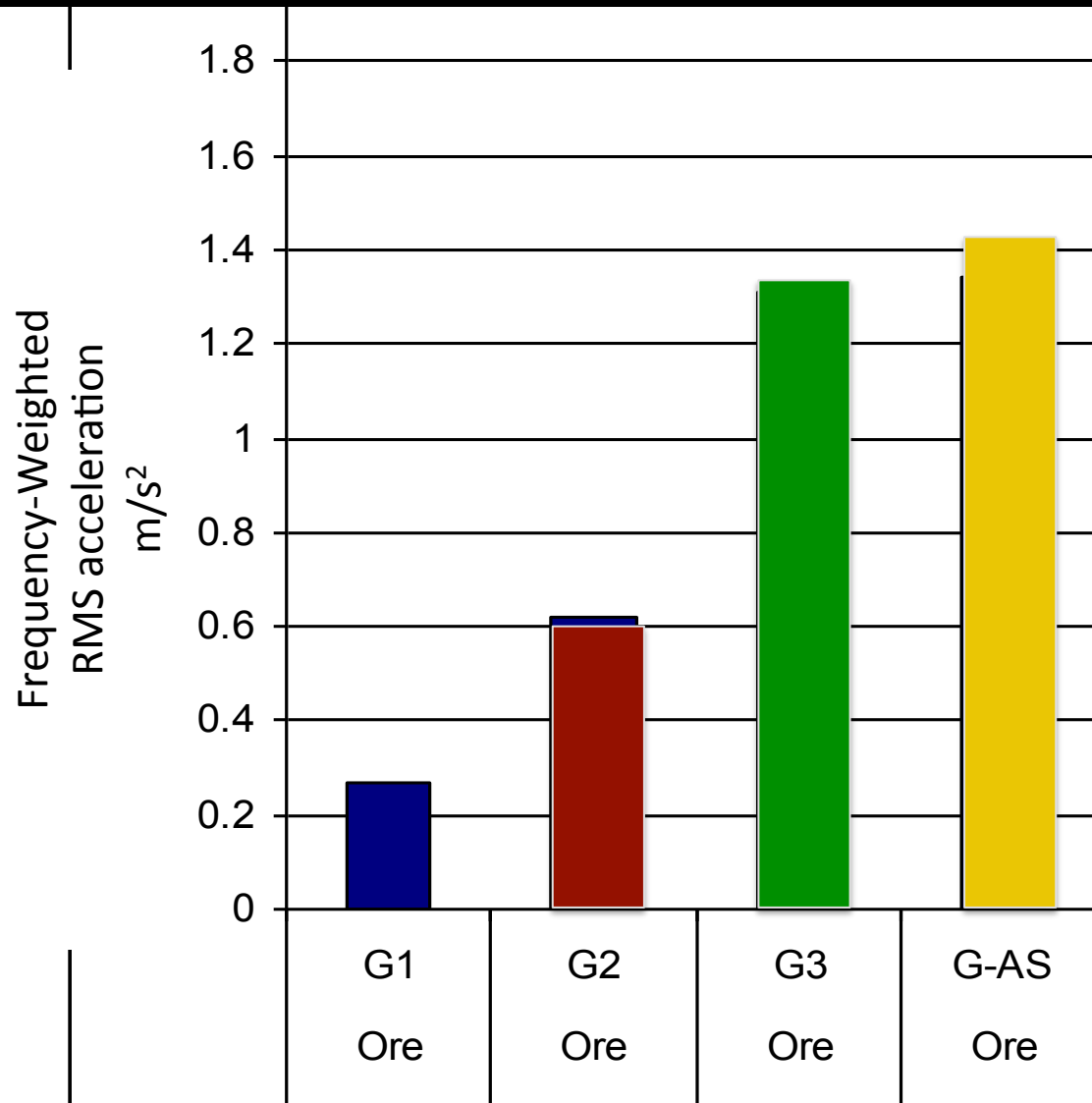
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http://www.deere.com/en_US/docs/html/brochures/publication.html?id=002d59a2#4

Operating Conditions

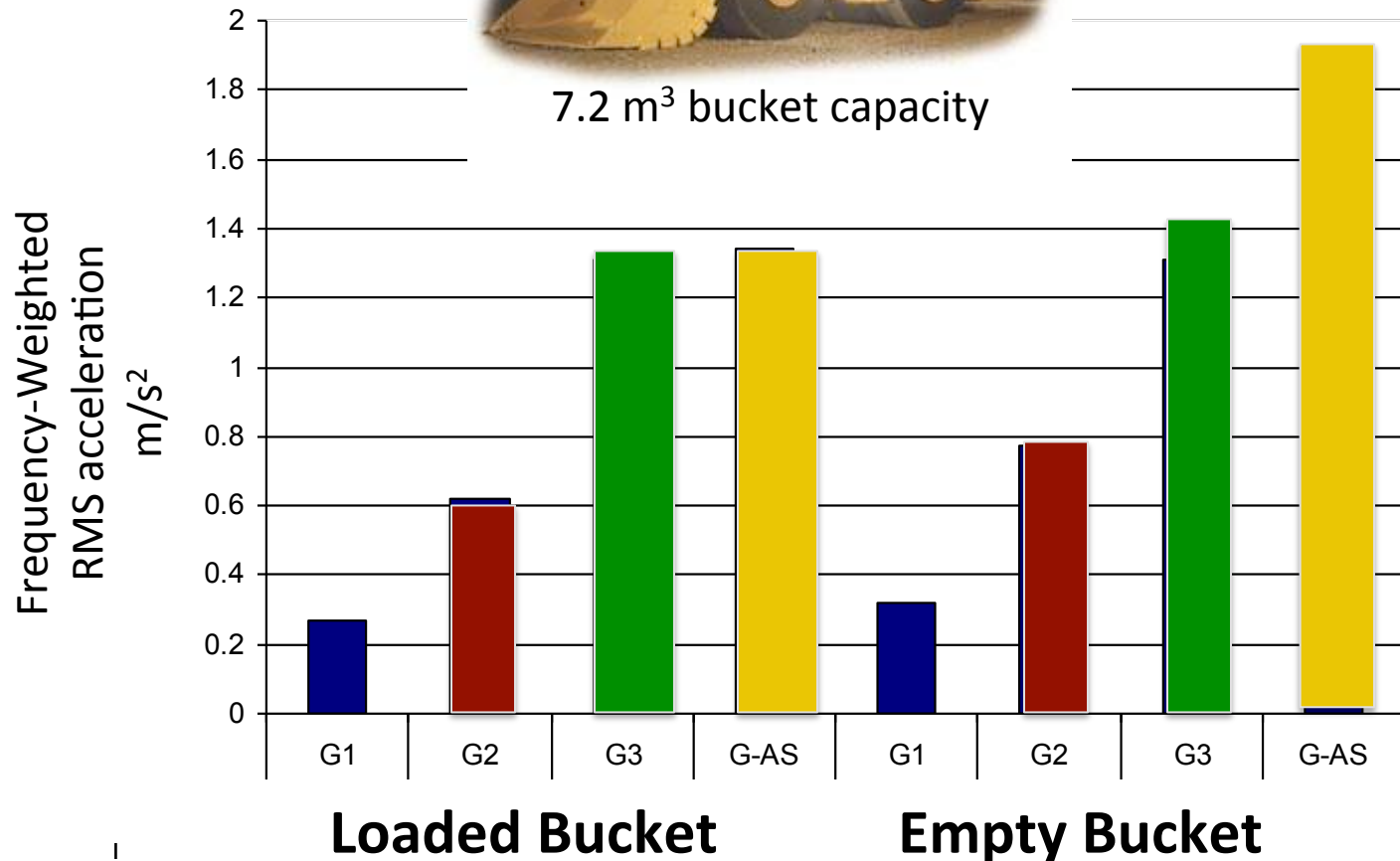
Monitor operating conditions and establish safe production targets

Frequency-weighted RMS acceleration DECREASED with a DECREASE in SPEED



7.2 m³ bucket capacity

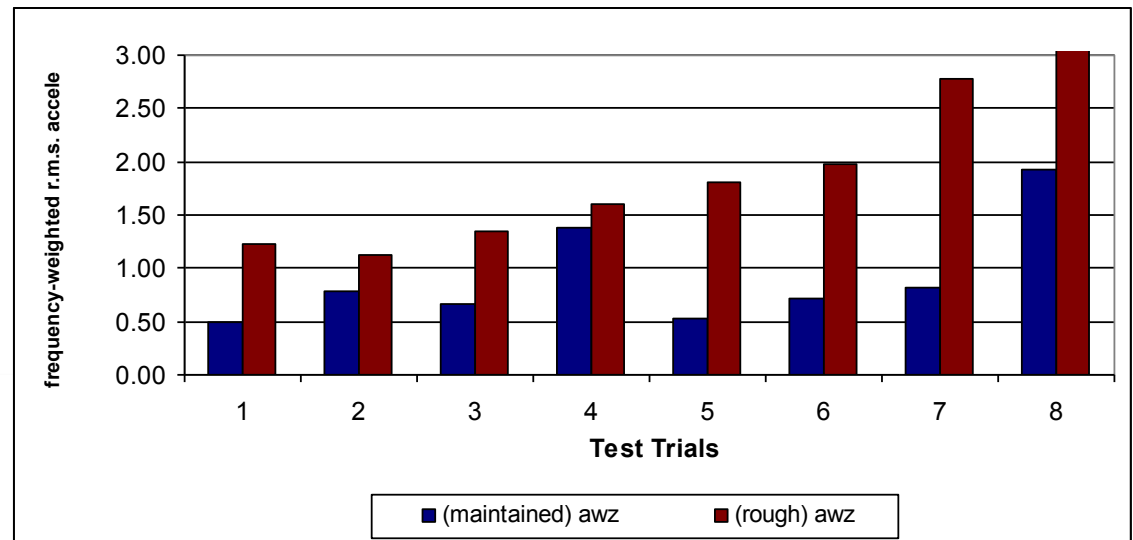
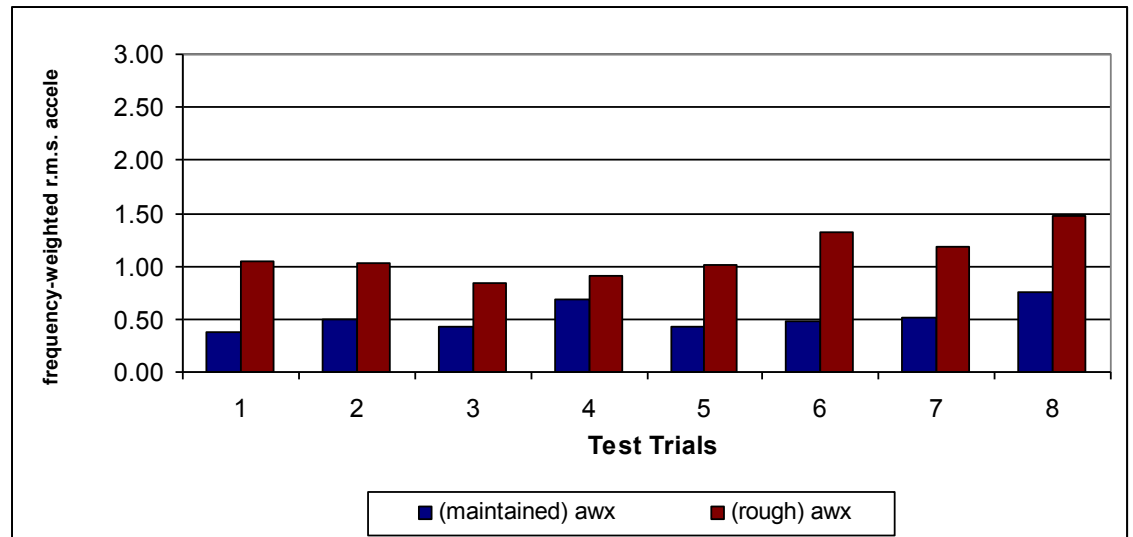
(Eger et al., 2011)



Frequency-weighted RMS acceleration DECREASED when driving loaded vs unloaded

(Eger et al., 2011)

Frequency-weighted RMS acceleration DECREASED on MAINTAINED roads



(Eger et al., 2011)

Seat Selection

- **Not all seats perform the same in all vehicles.**

Paddan and Griffin (2002) evaluated the vibration isolation efficiency for 100 seats found in 14 different types of vehicles and found **94 % of the vehicles evaluated would have improved vibration attenuation if a seat from one of the other vehicles tested in the study was used over the current seat.**

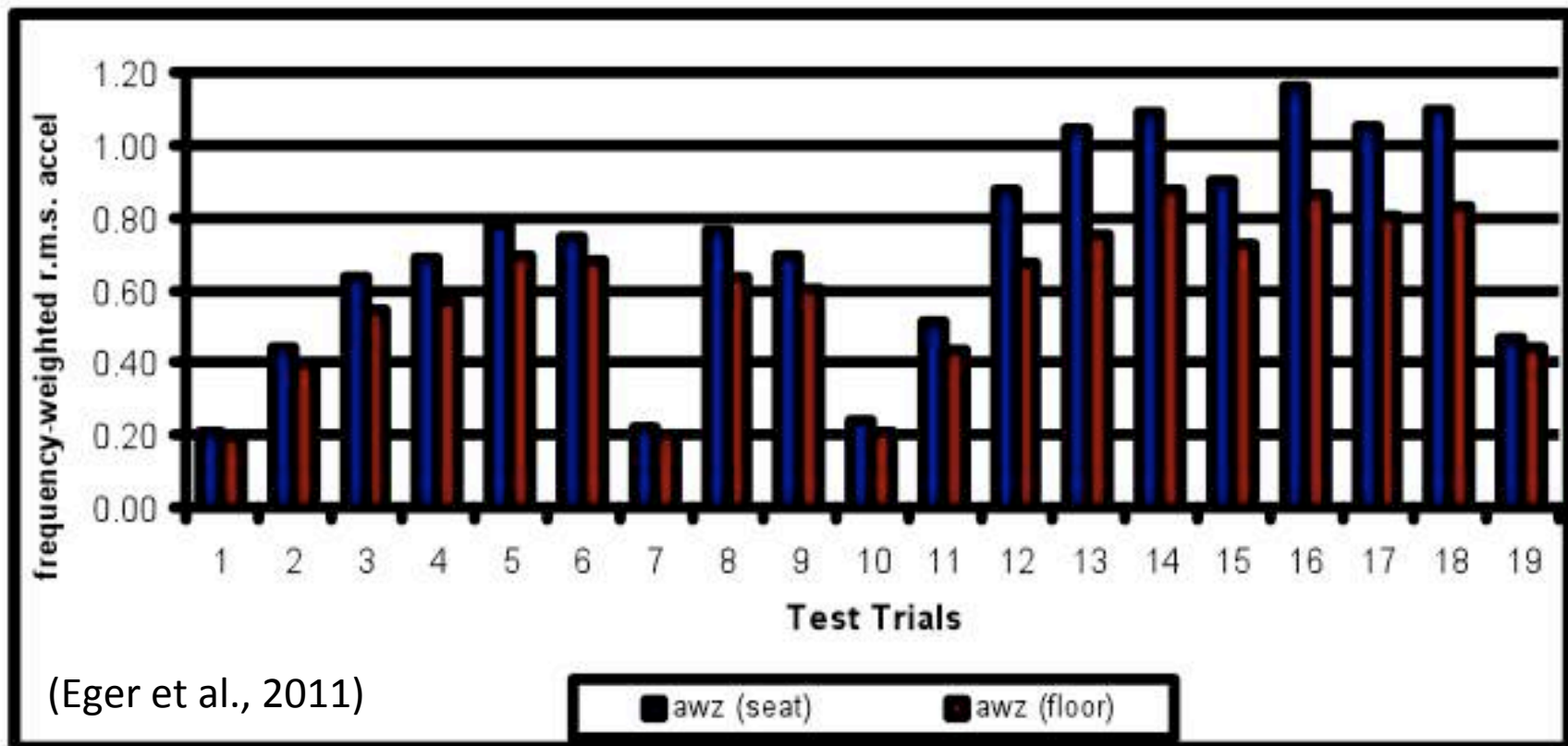
Seat Selection Matters

Example:

A new “ergonomic seat” amplified vibration

BLUE = seat

RED=floor



S.E.A.T. Seat Effective Amplitude Transmissibility

$$SEAT(\%) = \frac{vibration_{seat}}{vibration_{floor}} \times 100\%$$

A value greater than 1 = amplification

A rigid seat = ratio of 1.0

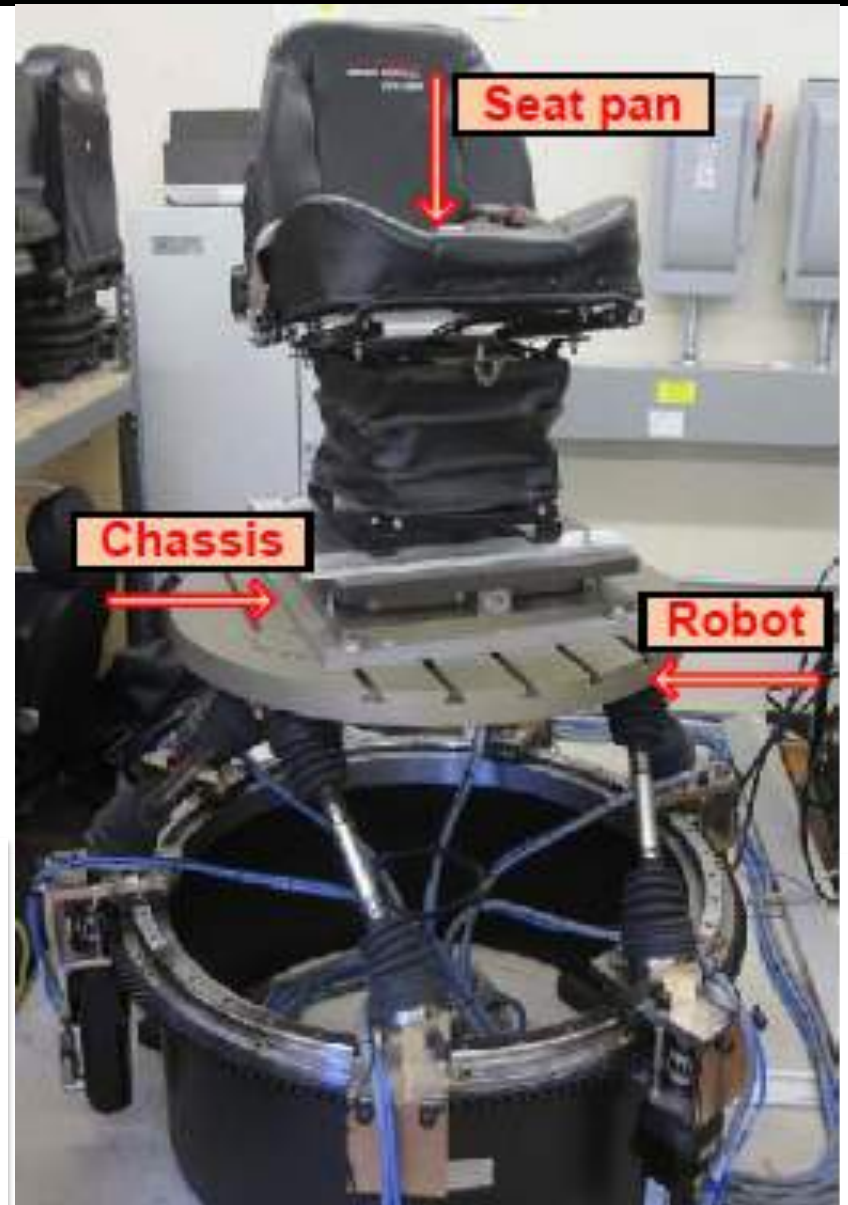
A value less than 1 = attenuation



Seat Evaluation

30 of the most common field vibration profiles from forestry, construction and mining were used to evaluate the seats

(Dickey et al., 2013)



Seat Evaluations

Industrial seats

	Manufacturers	Model
	Access mining services	Access 30019932
	Access mining services	Amobi SM2024
	Sears Manufacturing Co.	CAT EW013121
	KAB seating Ltd.	KAB 301
	KAB seating Ltd.	KAB 525

5 commercially available seats were selected for evaluation

(Xiaoxu et al., 2015)

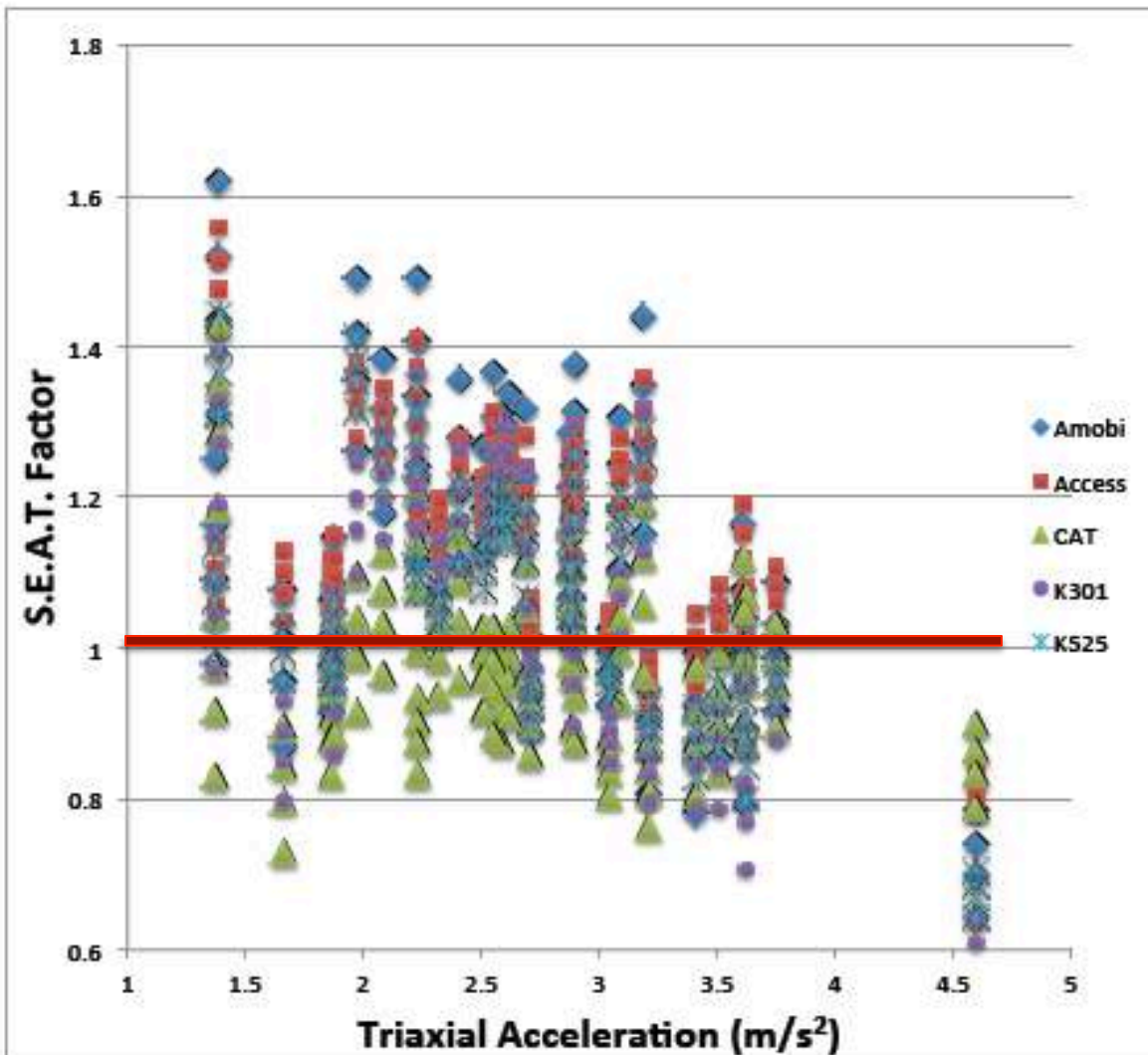


Figure 5. S.E.A.T. factors for five seats for each of the thirty most common vibration profiles. These data are arranged in order of increasing triaxial acceleration (vector sum of the rms magnitudes of the translational accelerations). Each symbol on the figure represents the response of one specific BMI group, and accordingly the graph appears to be composed of clusters of four symbols for each vibration exposure. Recall a S.E.A.T. value less than 1 suggests the seat is effective at attenuating the input vibration.

What does this mean?

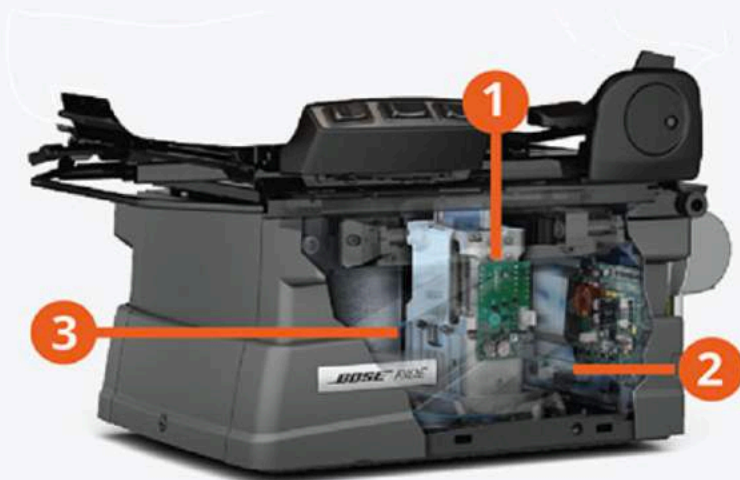
Based on the vibration profiles the CAT seat generally performed better.

(Xiaoxu et al., 2015)

New Seat Technology: Bose Ride Active Suspension Seat

How it Works

- 1 SENSE** - Precision sensors detect unwanted motion thousands of times per second.
- 2 ANALYZE** - High speed computer uses proprietary Bose algorithms developed over 25 years of research to determine the optimal response.
- 3 COUNTERACT** - Proprietary electromagnetic motor positions the driver to counteract unwanted motion.



<http://www.boseride.com/>

Bose Ride Active Suspension Seat significantly reduced WBV exposure in long-haul transportation

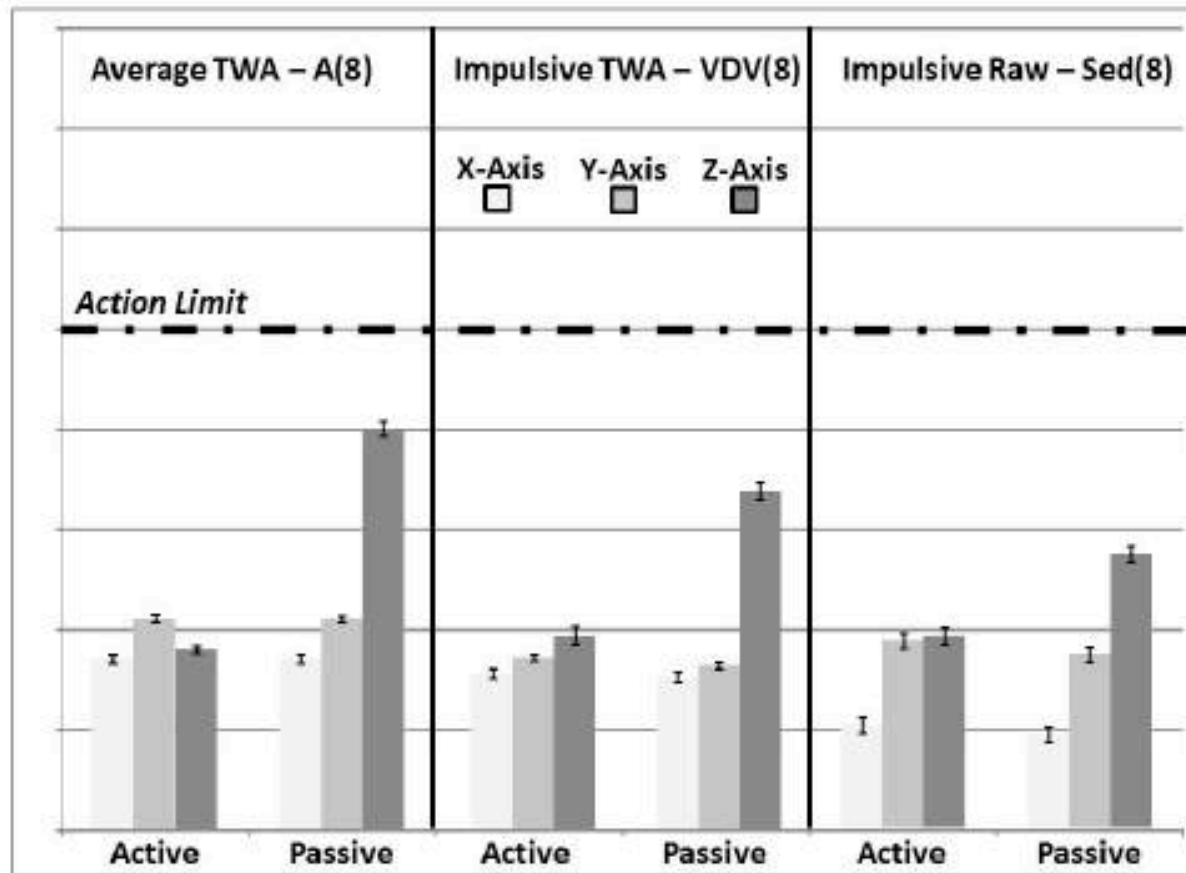


Figure 2: 8-Hour equivalent truck exposure by axis and seat (n=16).

Strategies to Improve Posture

Recall: increased low-back injury risk when non-neutral postures are combined with WBV exposure

- Redesign the cab to enable the operator to rotate the vehicle seat and controls
- Improve line-of-sight
 - Improve cab ergonomics
 - Secondary viewing devices

Examples: Construction Equipment

Seat/cab rotation to improve posture

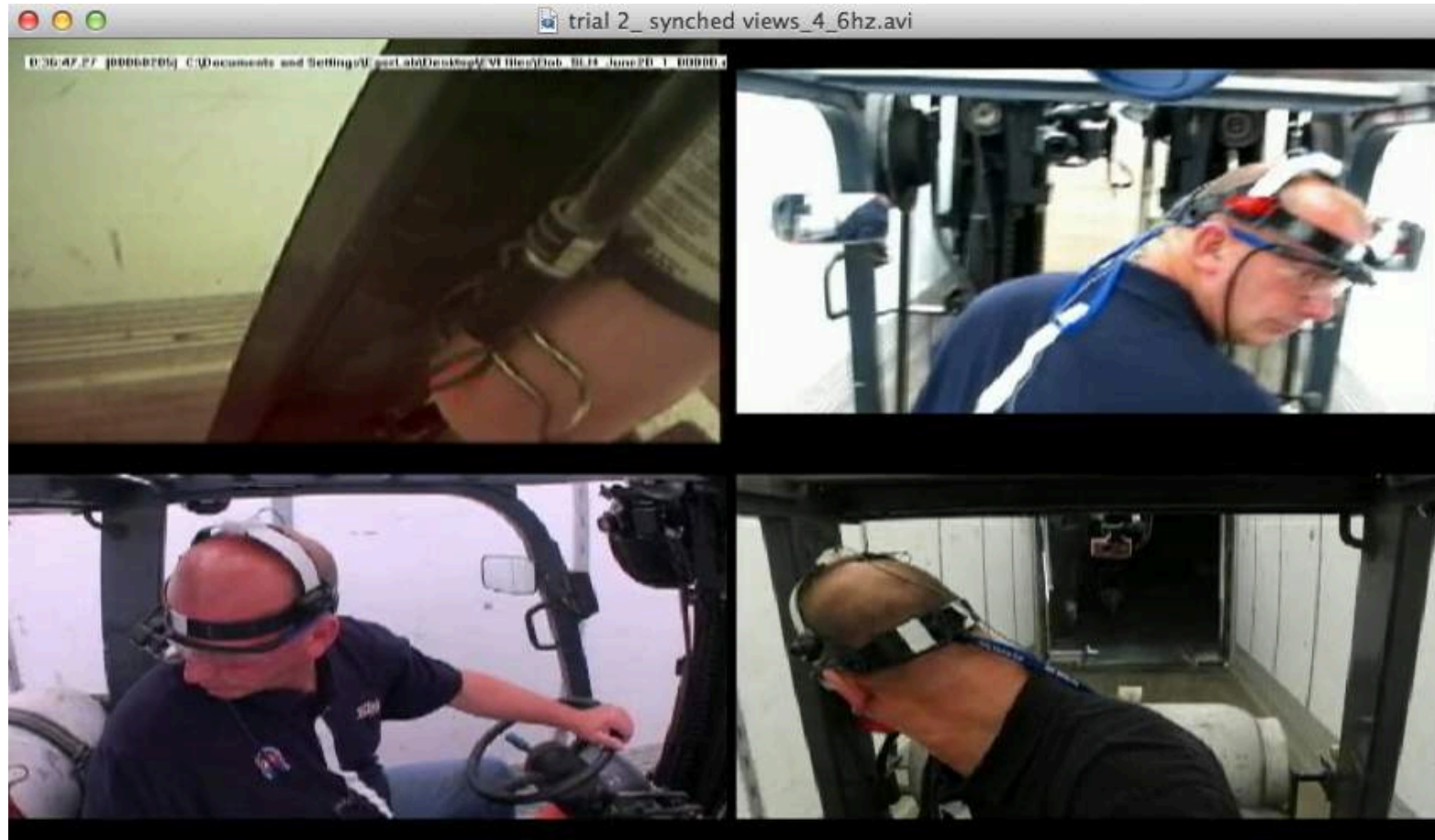


Spacious seat legroom

The cab features more room around the seat, making turning and position change from loader to excavator quicker and easier. More room between the seat and cab side. More legroom around the excavator controls.

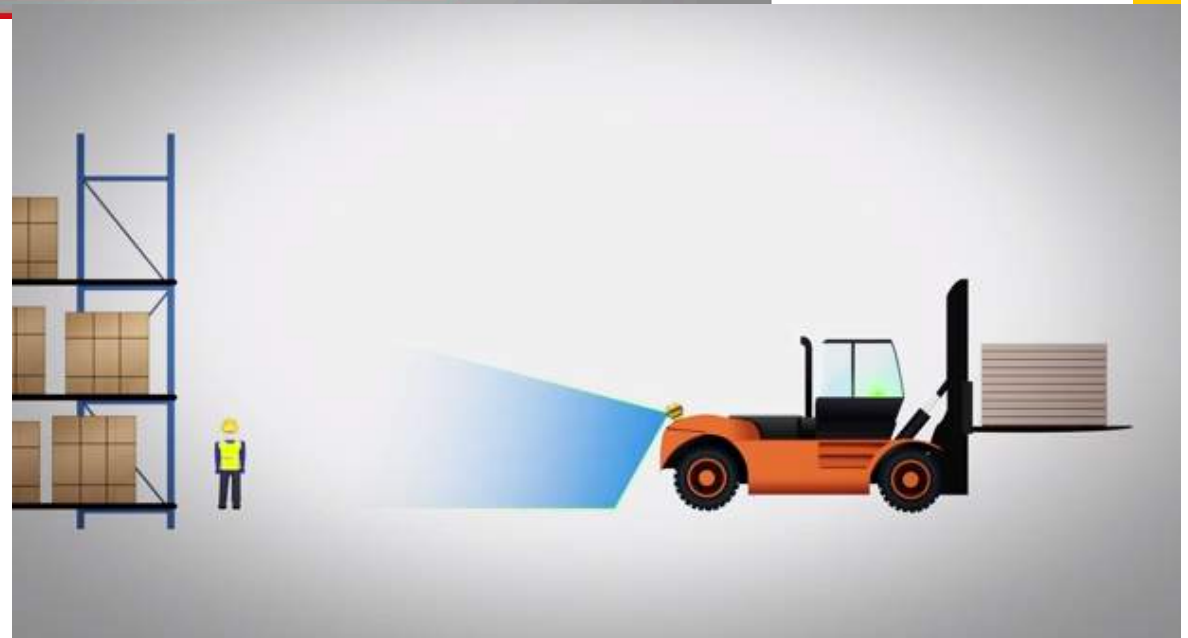
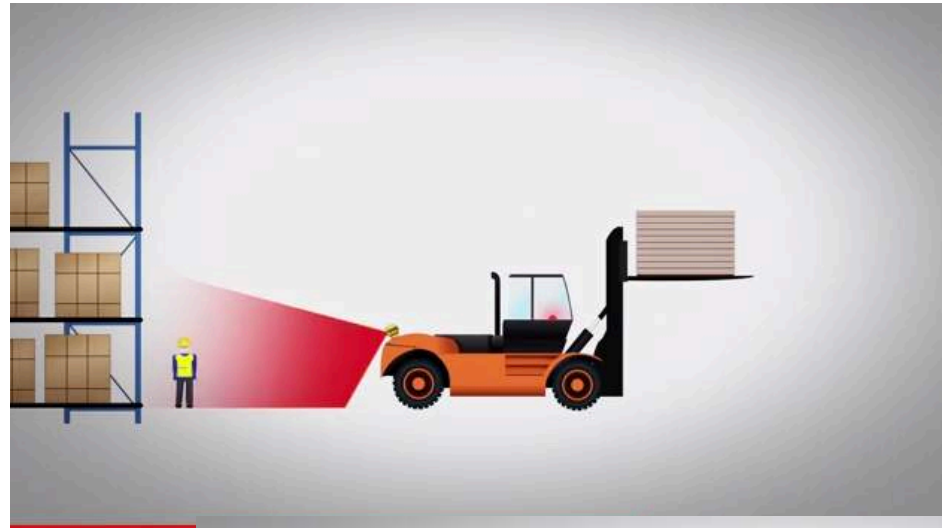
Field Study (*Minerals* **2013**, 3, 145-164; doi:10.3390/min3020145)

- Eye-tracking to evaluate line of sight (bottom left image)
- Three cameras to evaluate posture



Example Technology: Blaxtair

Camera system with an algorithm to detect pedestrians



<https://blaxtair.com/>

Monitor WBV as part of a WBV Exposure Management Plan

iOS Application and Ipad

The application can be downloaded for free from the App Store



WBV Measurement: Recording Details

Consider recording the following information so you can compare with published manufacturers' data:

- the type of equipment (e.g. fork-lift truck)
- the class of equipment (e.g. power or size)
- the power source (e.g. electric or combustion engine)
- any anti-vibration features (e.g. suspension systems suspended cab, seats)
- the task the vehicle was used for when producing the vibration information
- the speed it was operated at
- the type of surface it was run on

How to Use the WBV Measurement Application



SELECT the WBV icon to launch the app

SELECT 'New Trial' to begin a new measurement period

ENTER Trial Information, SET exposure duration at default 8 hours, SET maximum time per sample to 20 mins, ENTER additional comments

TAP "Start/Stop Trial" tab

A screenshot of the WBV Measurement Application interface on an iPod. The screen shows a 'Trial' form with the following fields and controls:

- Trial Duration:** 00:00:00 (highlighted with a yellow circle)
- Start/Stop Trial:** A toggle switch (highlighted with a yellow circle)
- Trial Name:** ABC
- Equipment:** HT 930E
- Task:** Removing spoil
- Exposure Duration:** 10 hours (with minus and plus buttons)
- Maximum Time per Sample:** 20 minutes (with minus and plus buttons)
- Comments:** (empty text field)

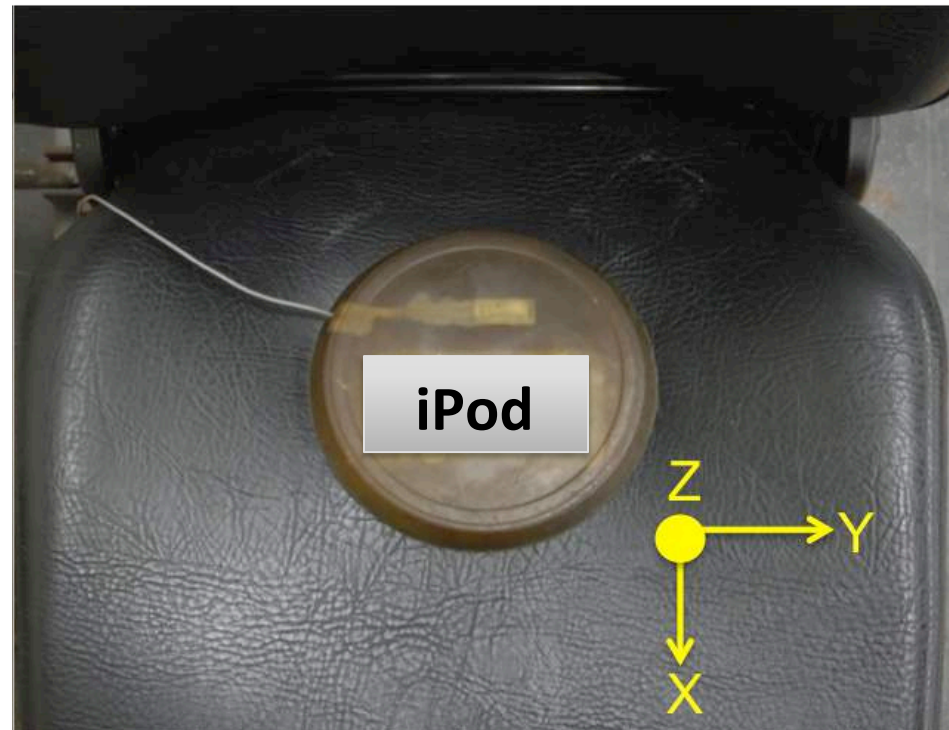
How to Use the WBV Measurement Application



PLACE the iPod Touch screen face down on the seat pan; align as best you can with the boney part of the buttocks*

POSITION the iPod so that the length of the iPod Touch is parallel to the edge of the seat

SECURE with adhesive tape (ex. duct tape)



How to Use the WBV Measurement Application

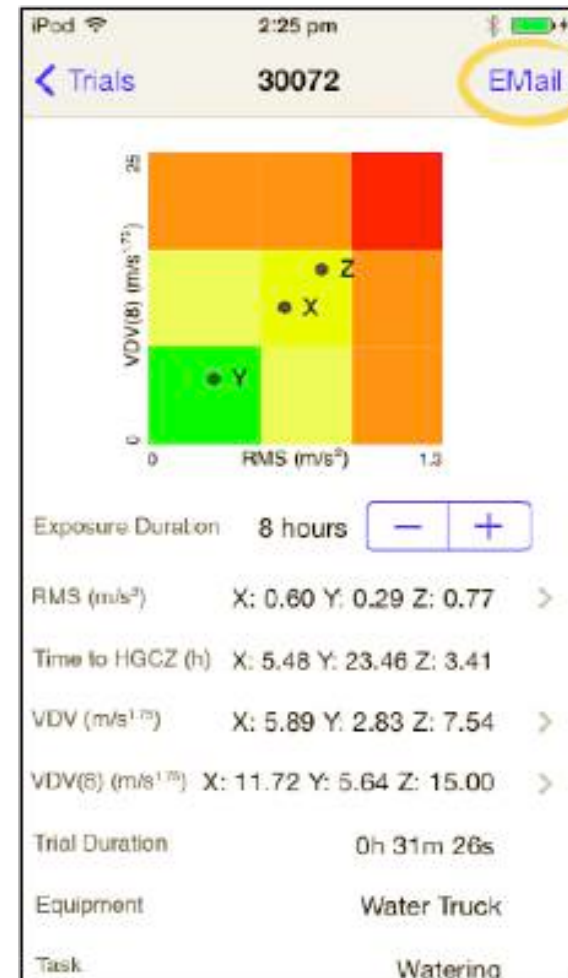


TAP 'Start/Stop' tab

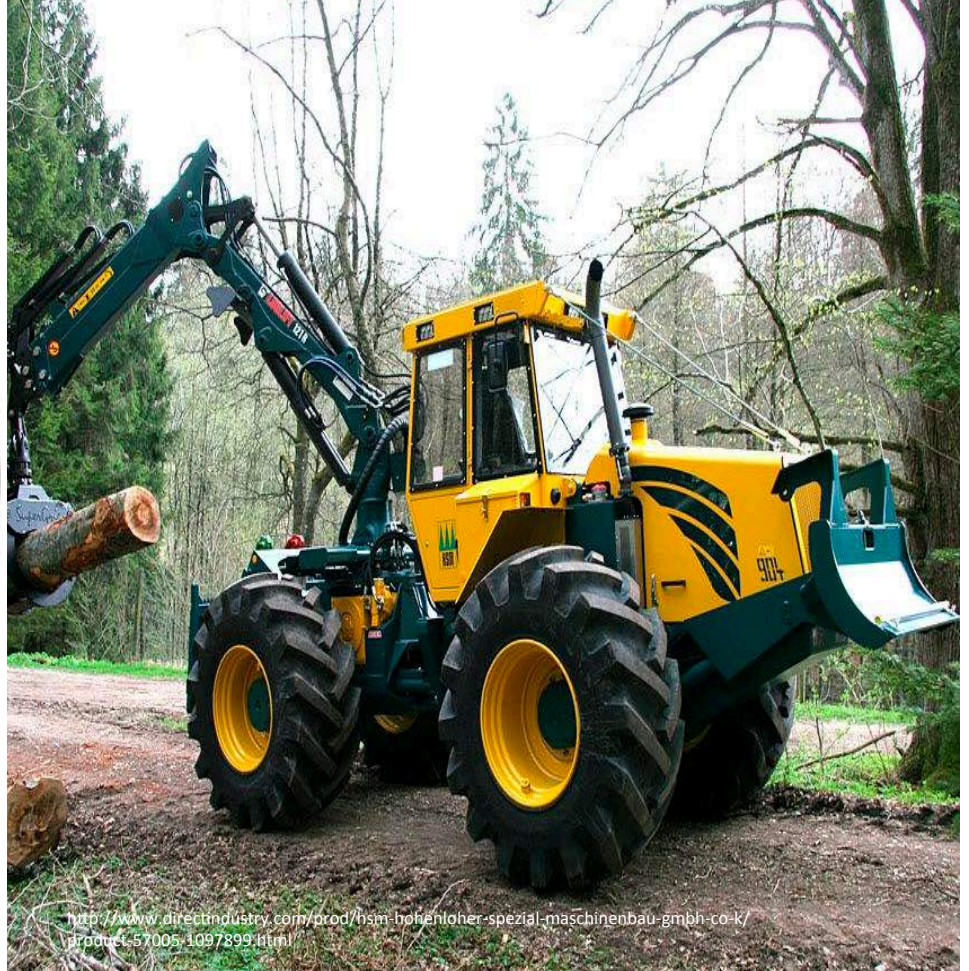
CALCULATING will appear on the screen while the acceleration data are being processed

Search and SELECT the trial data you wish to view

You can choose to EMAIL the trial data if there is WiFi available or manually through iTunes



Questions and Discussion



Although we have presented many of the **challenges with vibration exposure reduction** in isolation – the issues associated with equipment design, operation and management are more **complex** and **interrelated**.

Reducing adverse health effects associated with vibration exposure will require a **multifaceted approach** involving participation of **workers, industry leaders, equipment manufacturers, researchers, and health care providers**.

Helpful Resources

EU Good Practice Guide WBV

Guide to good practice on

Whole-Body Vibration

Non-binding guide to good practice with a view to implementation of Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations).

[https://www.google.ca/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=EU+good+practice+guide+to+WBV&*](https://www.google.ca/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=EU+good+practice+guide+to+WBV&*>)

Whole body vibration



Advice on reducing the risks of back and muscle pain caused by shocks/vibrations when driving certain types of vehicle.

 [Whole body vibration](http://www.hse.gov.uk/vibration/index.htm)

<http://www.hse.gov.uk/vibration/index.htm>

Standards

- International Organization for Standardization, 1997. ISO 2631-1 Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration —Part 1: General Requirements, Geneva, Switzerland. Reference number ISO 2631-1:1997(E). (Confirmed 2014)
- American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) -2017
- International Organization for Standardization (ISO): *Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 5: Method for evaluation of vibration containing multiple shocks* (ISO 2631-5). [Standard] Geneva, Switzerland: ISO, 2004.
- Directive 2002/44/EC of the European parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

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Webinar Reference

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To reference:

Eger, T., and Killen, W. Whole-body Vibration Exposure. Webinar. CROSH Lunch&Learn Series, March 30, 2017.

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CROSH Vibration Research Program Funding



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