Evaluation and assessment of building vibration with respect to human response: a summary of standardised methods

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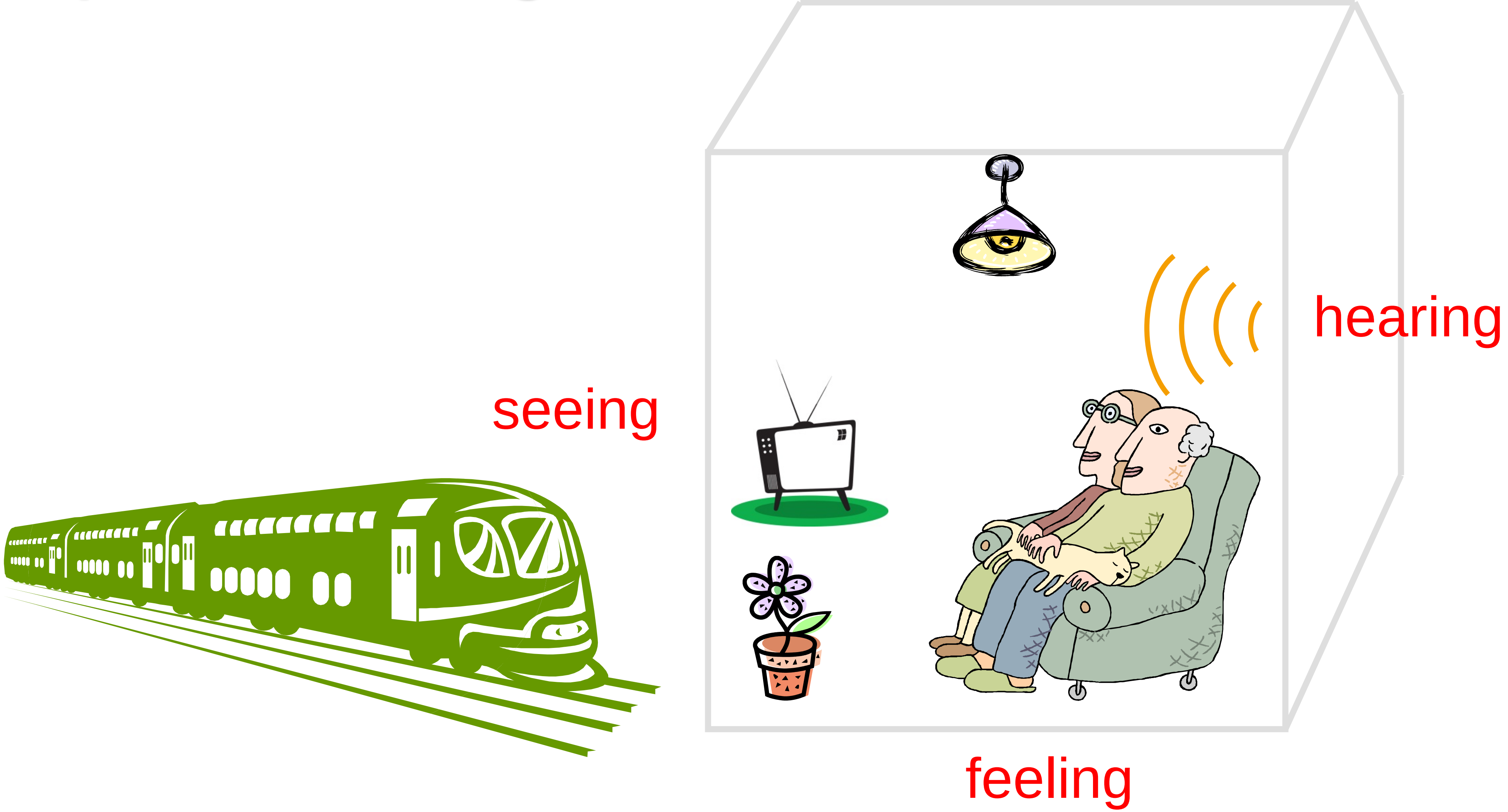
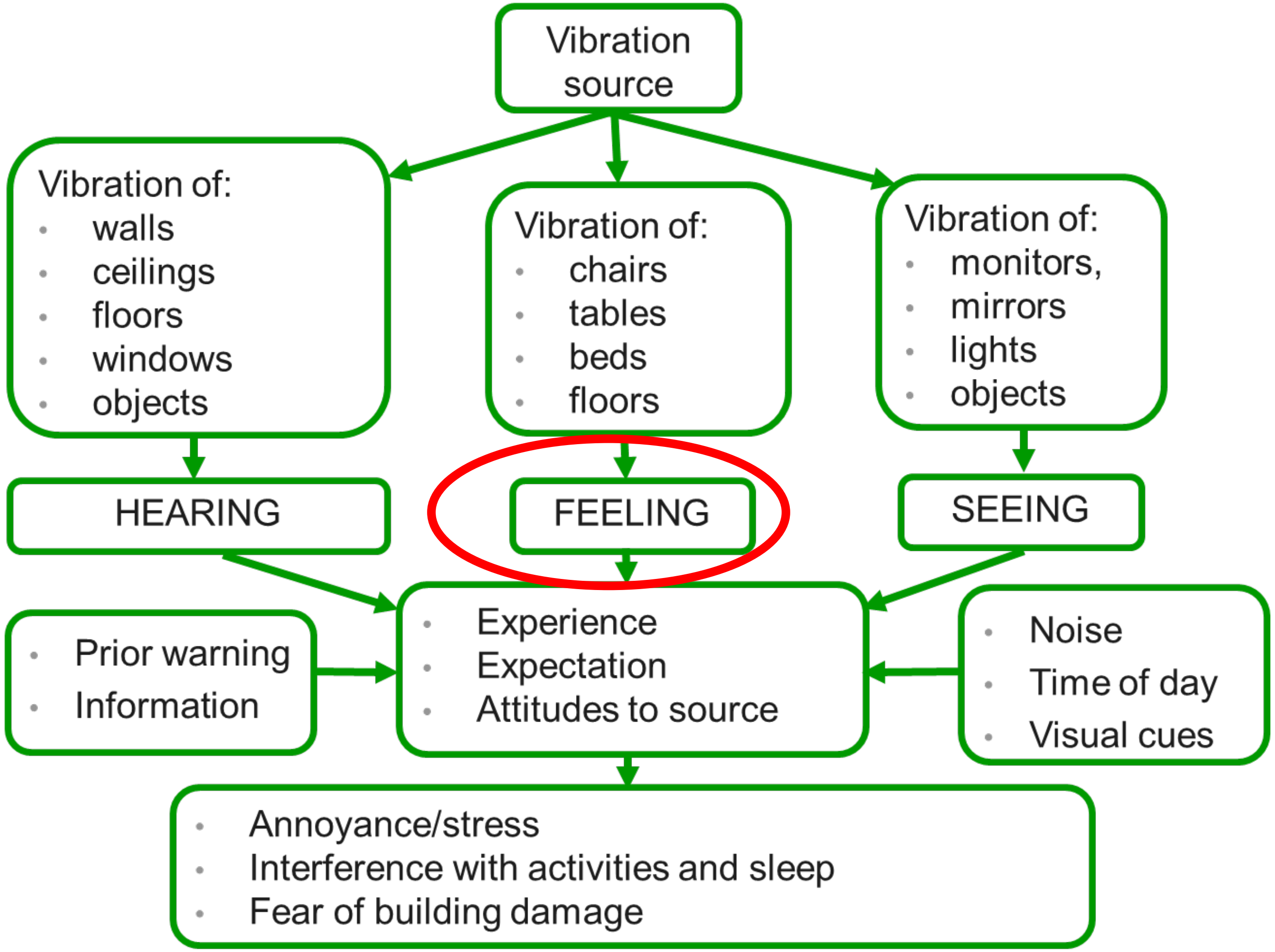
Presentation contents

- Introduction: perception of building vibration
- Vibration evaluation:
  - Effects of frequency, axis, magnitude, duration
  - Average, dose and peak
  - Standards
  - Laboratory studies
- Vibration assessment
  - Standards
- Laboratory and field studies

Perception of building vibration



Factors affecting acceptability



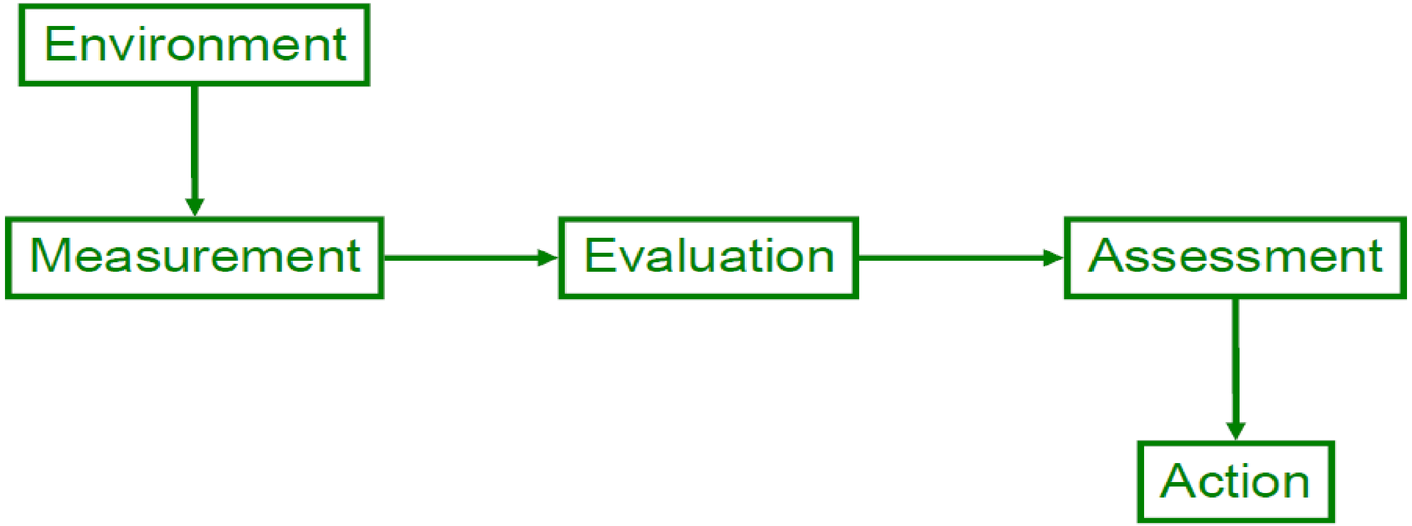
Human response to feeling building vibration

- Responses to feeling building vibration may be provoked at vibration magnitudes at and slightly above the perception threshold.

- Some may consider vibration in a building that is just perceptible excessive. Others may find it acceptable, but intolerable at magnitudes only slightly greater than perception threshold.

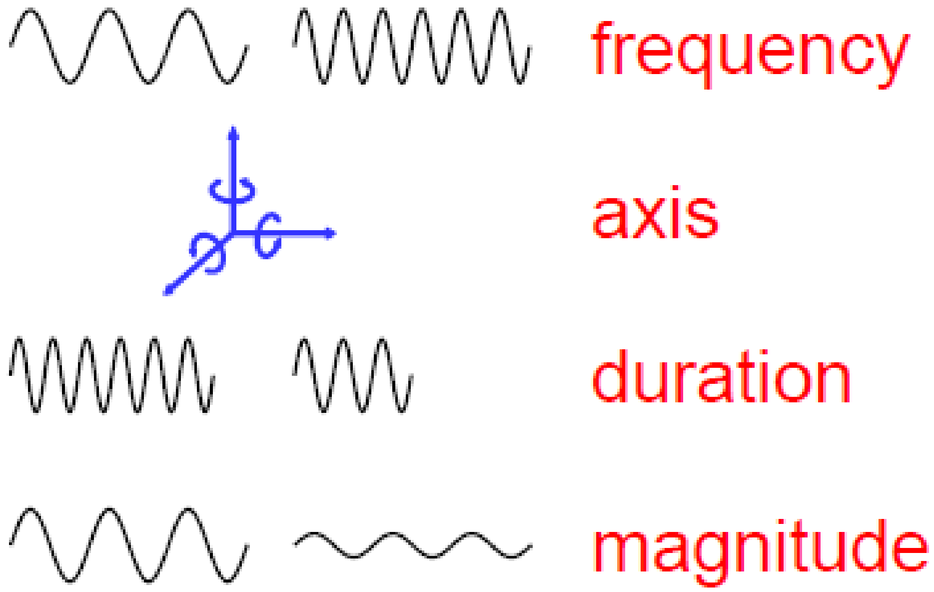
- Human perception at low magnitudes can be predicted from experimentally determined perception thresholds and equivalent comfort contours.

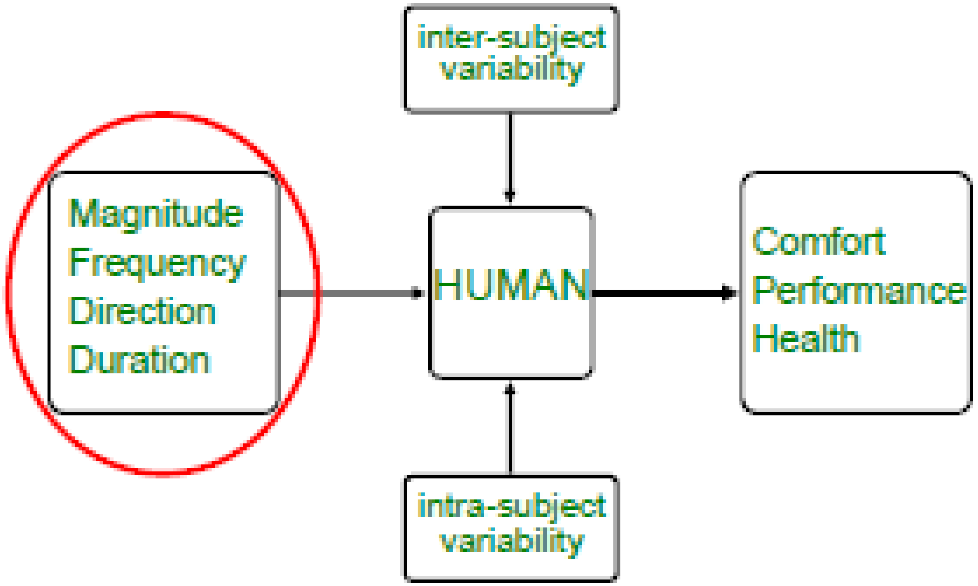
Predicting human response to feeling vibration



- Measurement - Record the physical characteristics of stimulus
- Evaluation - Express severity of stimulus by a single value
- Assessment - Identify the likely consequences of exposure to the stimulus.

Vibration evaluation





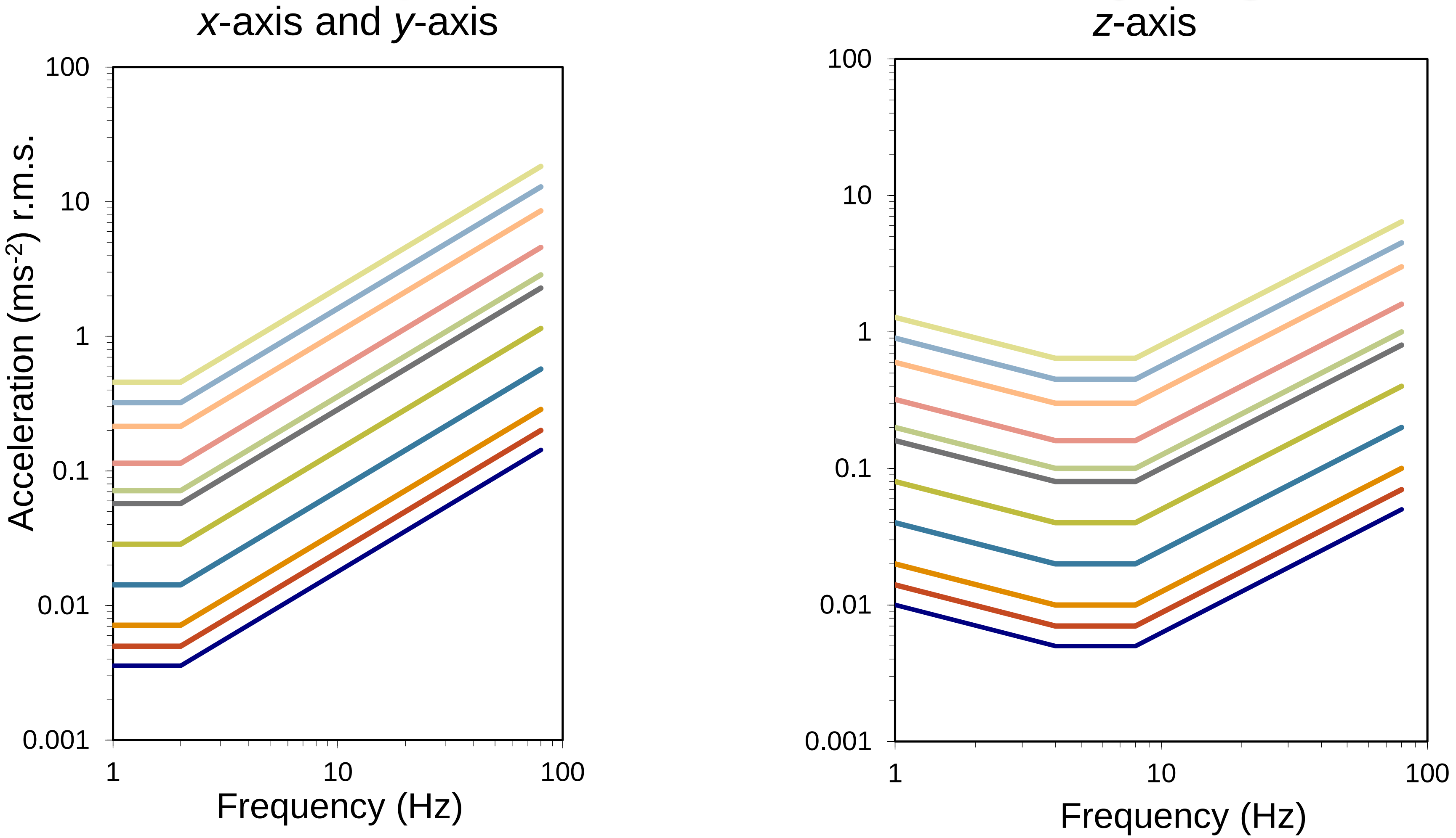
Laboratory studies versus field studies

- Laboratory studies – useful for:
  - Systematic study of each variable in turn – effects of each variable (frequency, magnitude, direction, duration, etc) and relative importance of variables
  - Simulation of the controlled 'real' vibration environments – relative acceptability of complex motions
- Field studies – useful for:
  - Comparisons of evaluation methods
  - Determining cause-effect / dose-response relationships
  - Assessments of absolute acceptability and limits

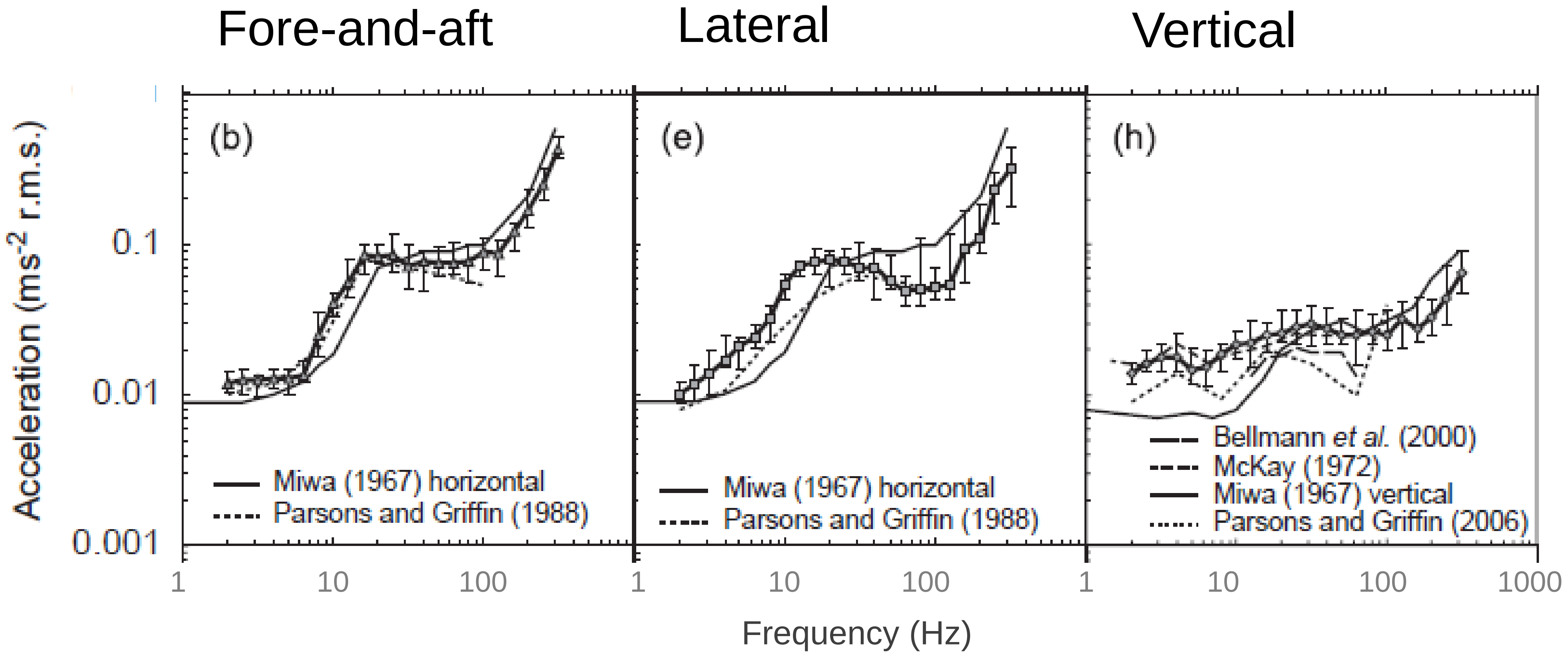
Frequency weightings

- Frequency weightings for each axis are defined in standards: BS 6472-1 (2008) and ISO 2631 Parts 1 and 2 (1997)
- Frequency weightings are derived from experimentally determined equivalent comfort contours and perception thresholds

BS 6472:1992
Baseline curves with multipliers to indicate satisfactory magnitudes



Studies of perception thresholds



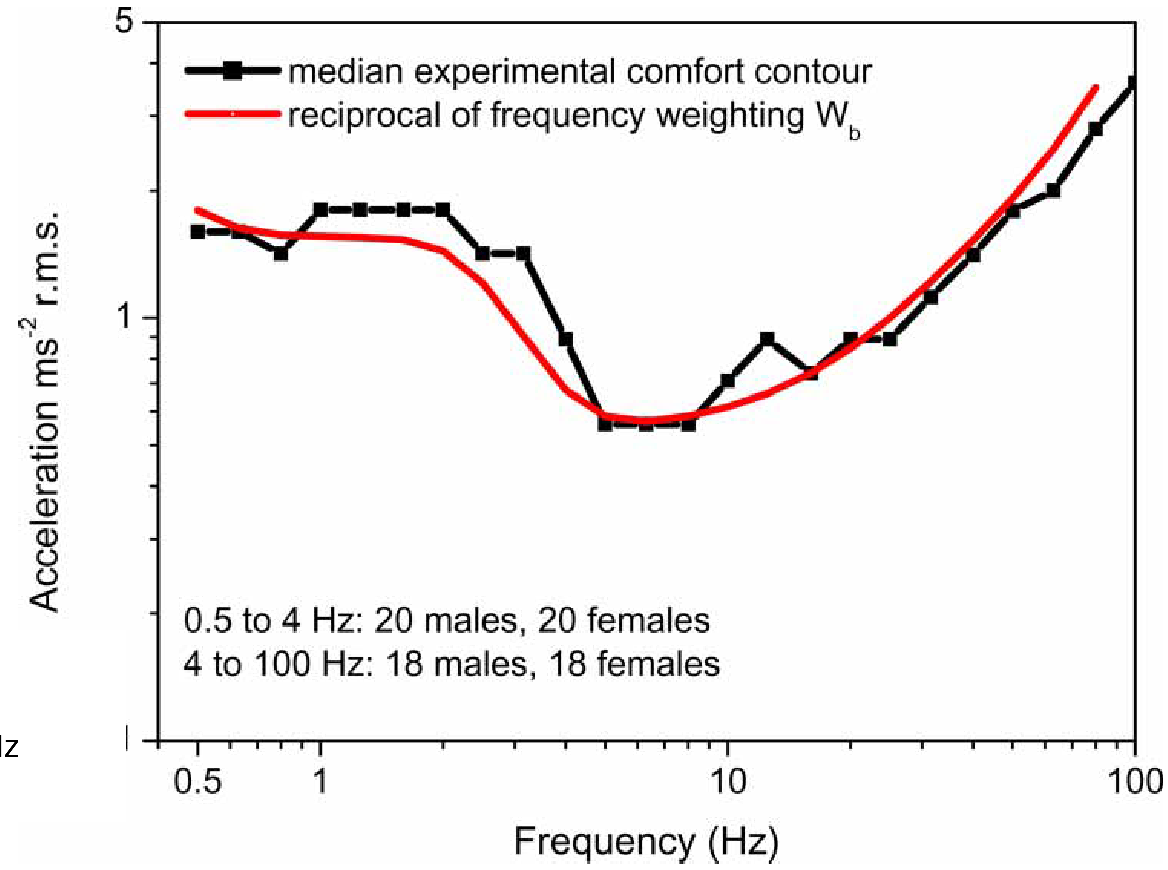
From Morioka and Griffin (2008) JSV 314, 257-370

Perception of vibration

- BS 6472-1 (2008) and ISO 2631-1 (1997):

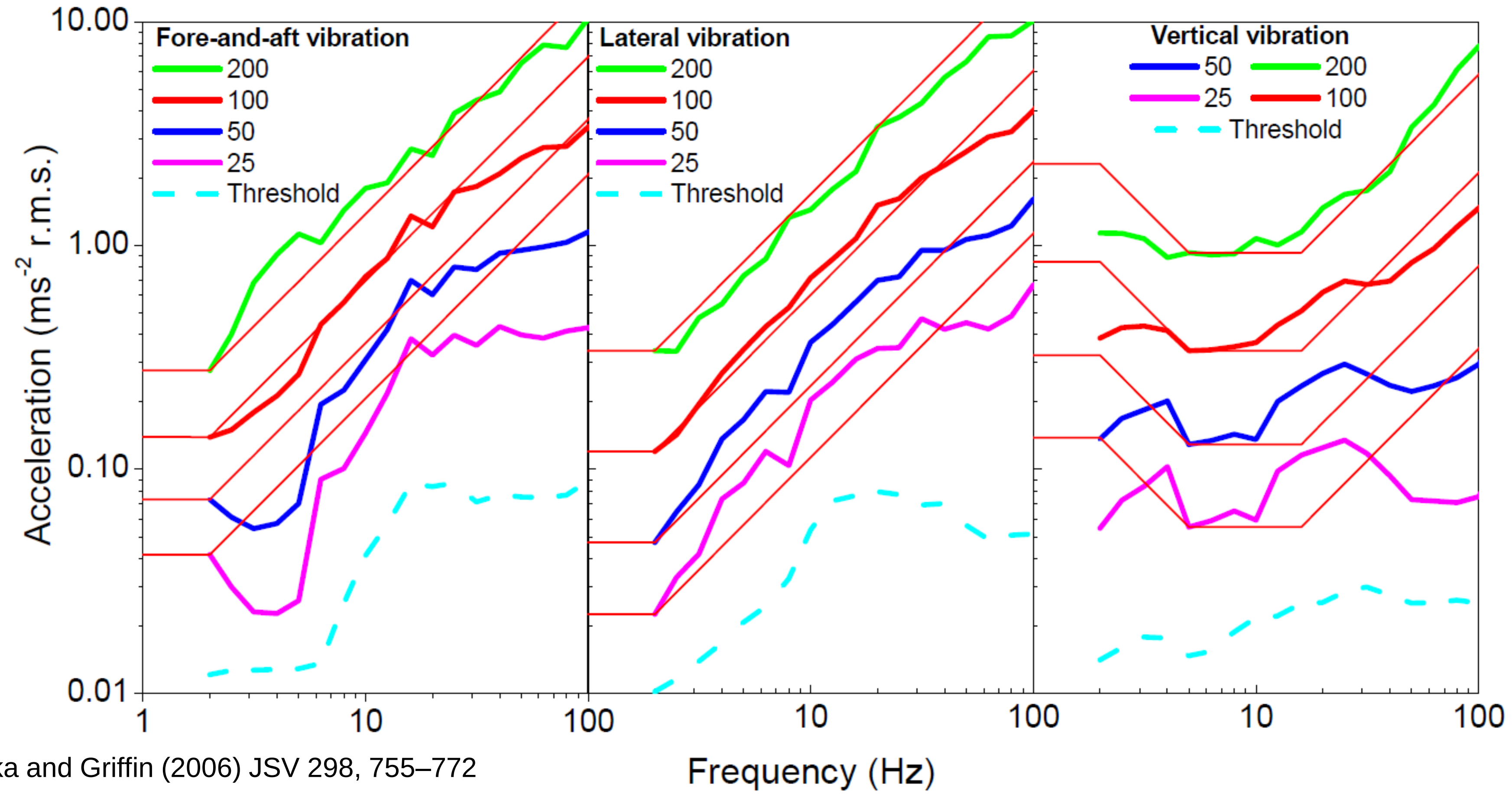
  50% of persons can just detect a weighted vibration of approximately 0.015 ms^{-2} peak with an inter-quartile range from about 0.01 to 0.02 ms^{-2} peak

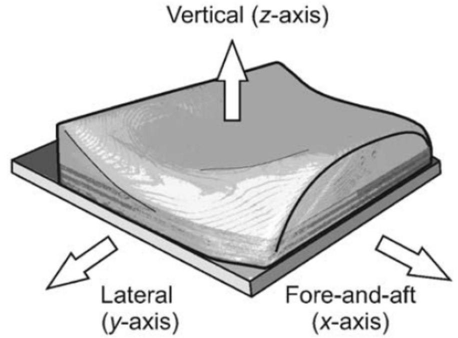
Studies of equal comfort contours: vertical seat vibration compared with W_b



Griffin *et al*. (1982): 2-100 Hz
Corbridge and Griffin (1986): 0.5-5 Hz

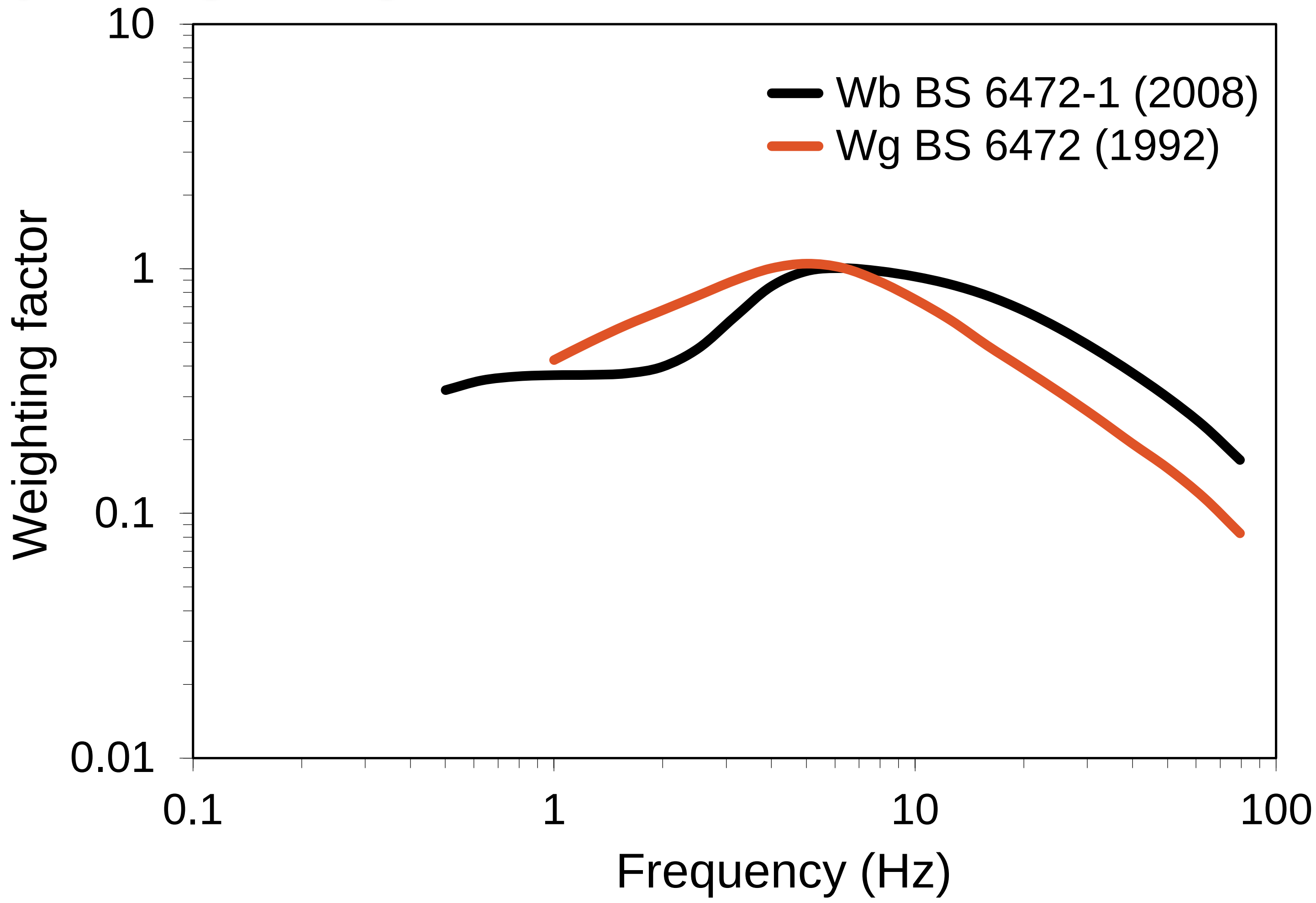
Median equivalent comfort contours and perception thresholds compared with W_b and W_d weightings





Morioka and Griffin (2006) JSV 298, 755–772

Frequency weightings for vertical vibration

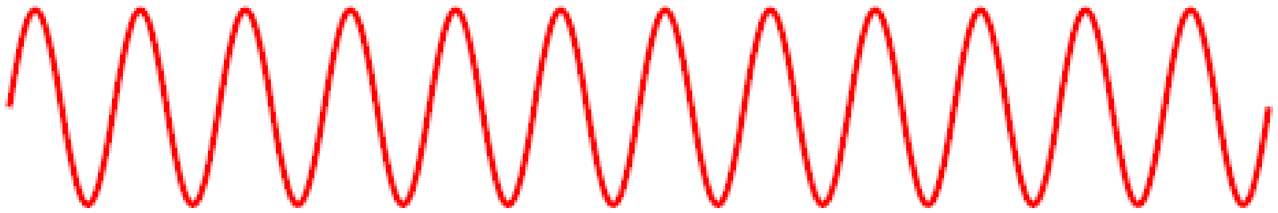


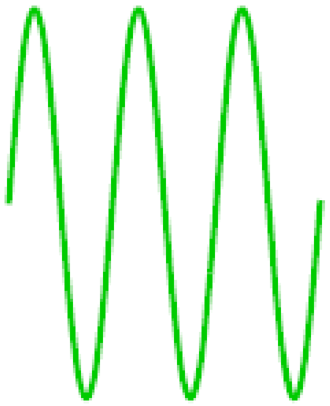
Evaluation methods

- Averaging methods:
  - r.m.s.
  - r.m.q.
- Dose method:
  - VDV
- Maximum method:
  - Peak velocity

r.m.s. averaging

$$\text{r.m.s. acceleration} = \left[\frac{1}{T}\int_0^T a^2(t)dt\right]^{1/2}$$





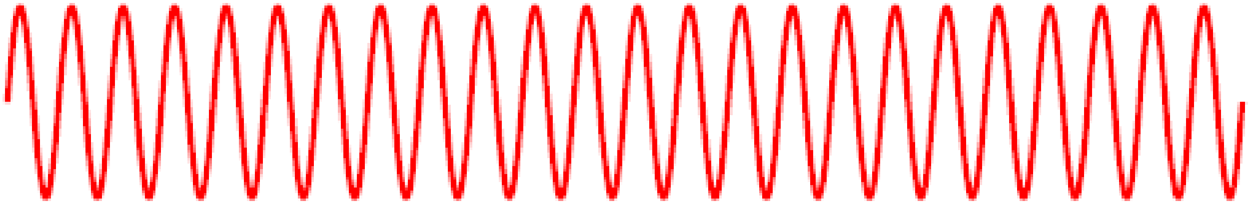
r.m.s. averaging:

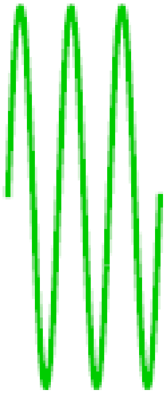
a^2t = constant

four-fold reduction in duration
corresponds to doubling magnitude

r.m.q. averaging

$$\text{r.m.q. acceleration} = \left[\frac{1}{T}\int_0^T a^4(t)dt\right]^{1/4}$$



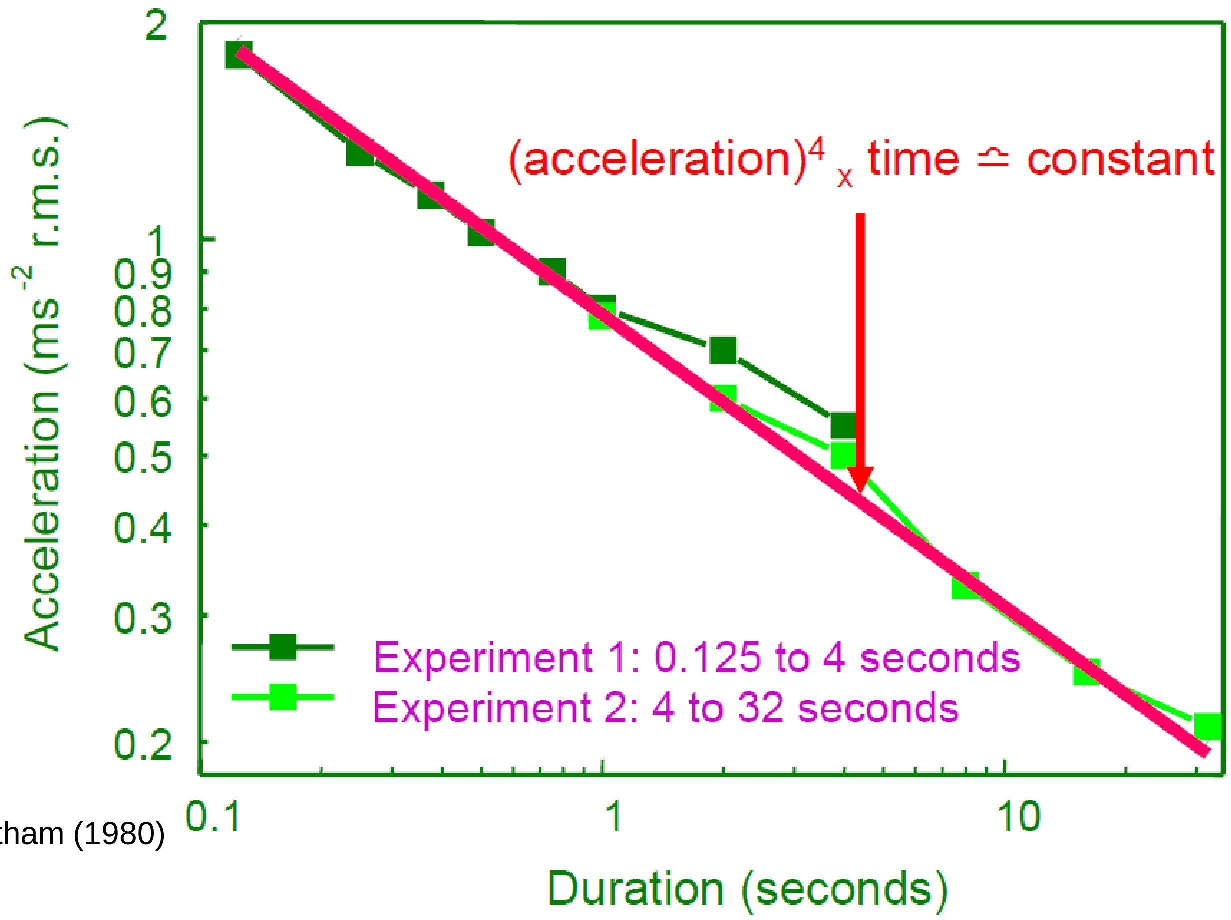


r.m.q. averaging:

a^4t = constant

sixteen-fold reduction in duration corresponds to doubling magnitude

Effect of duration and magnitude on vibration discomfort

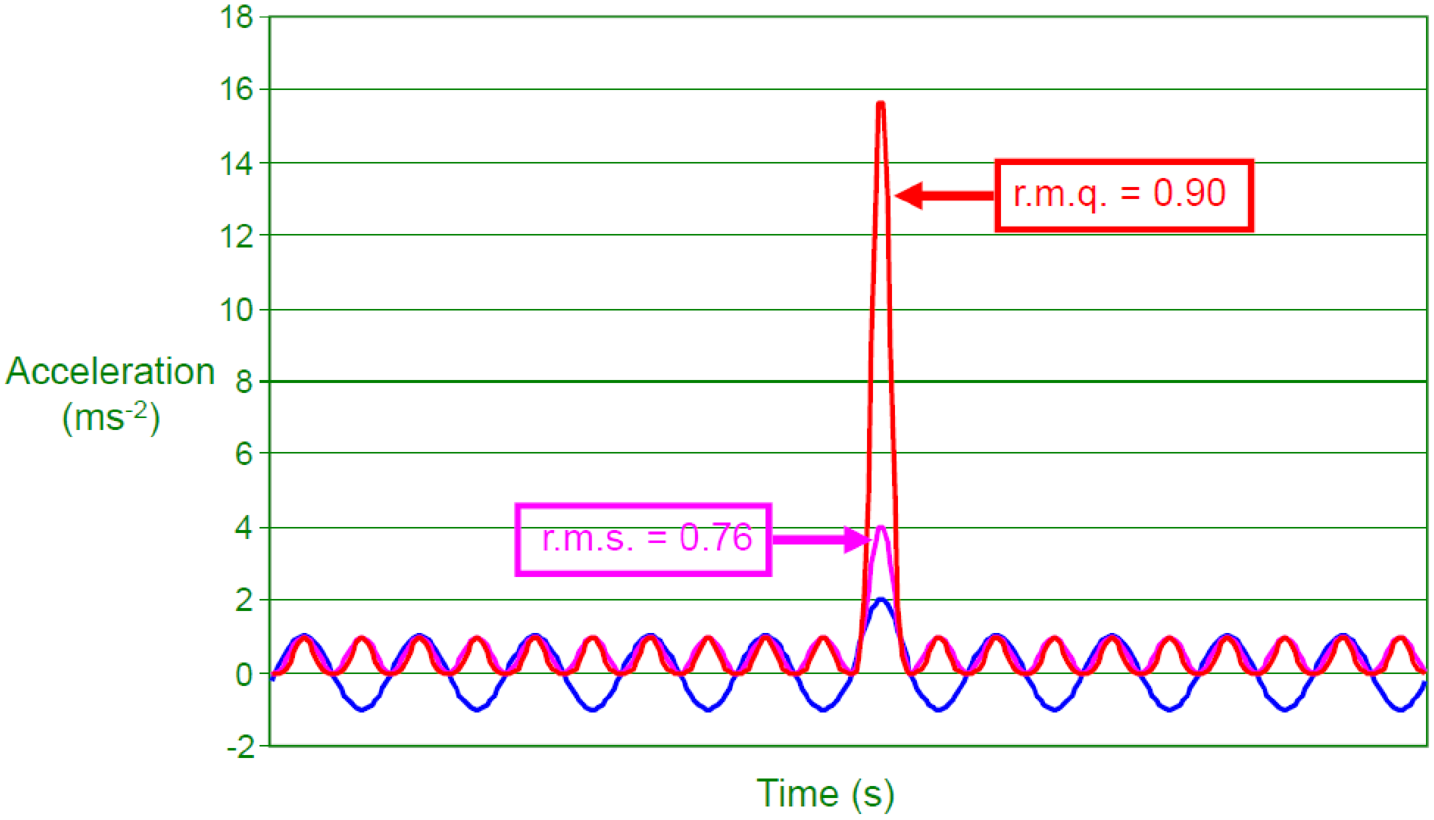


Adapted from Griffin and Whitham (1980)

Consistent with findings of studies of annoyance from intermittent trains (Howarth and Griffin, 1988)

r.m.s. and r.m.q.

r.m.q. gives more weight to occasional higher magnitudes than r.m.s.



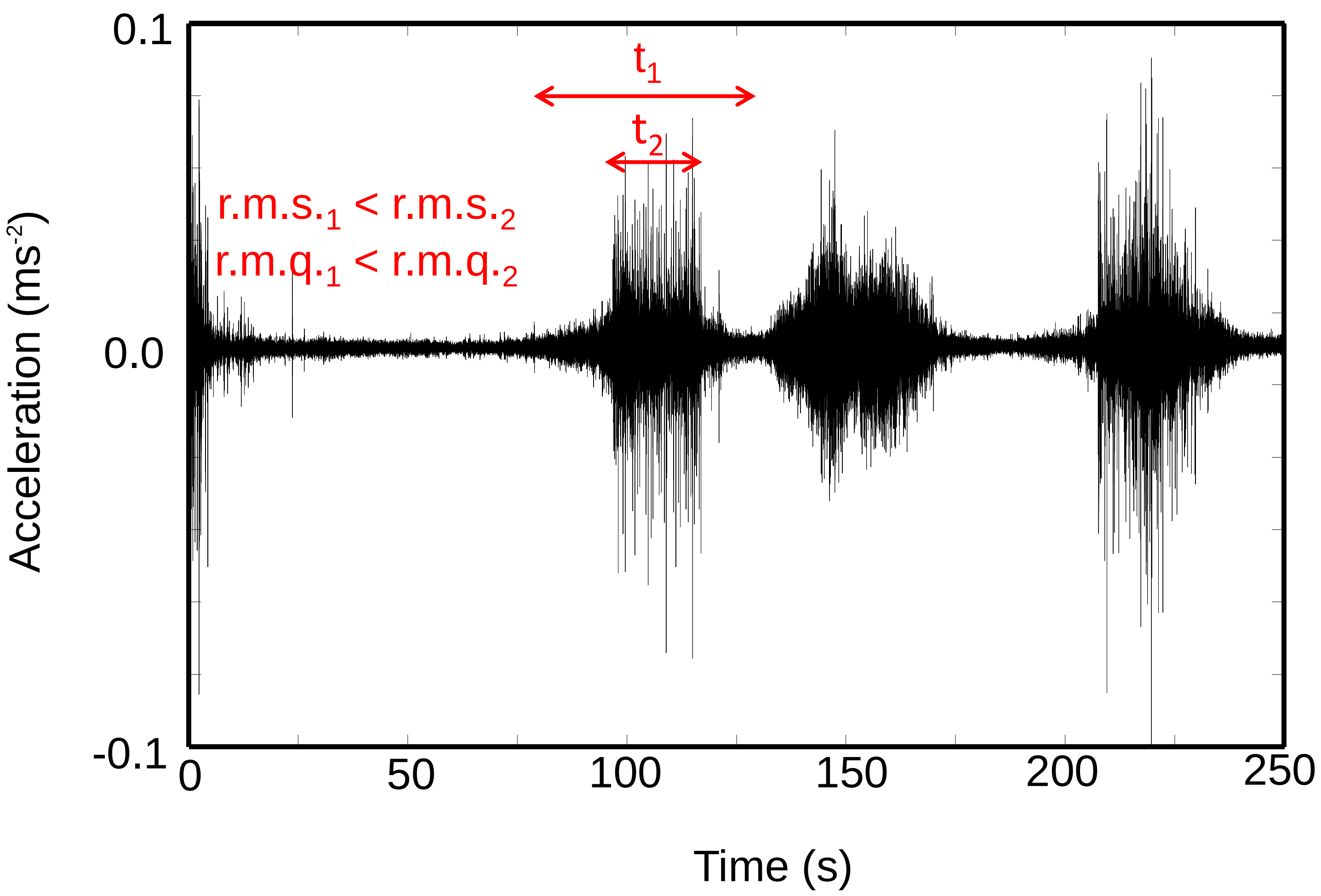
Consistent with Griffin, 1990; Howarth and Griffin, 1991; Ahn and Griffin, 2008

r.m.s. and r.m.q. averaging

- Building vibration is expected to be more unacceptable the longer it lasts.
- But r.m.q. and r.m.s. are averages so do not increase as duration increases
- Building vibration often consists of time-varying events and it is difficult to define start and end to determine r.m.s. or r.m.q.

r.m.s. and r.m.q. averaging

r.m.s. and r.m.q. depend on measurement period



The problem is averaging over the measurement period

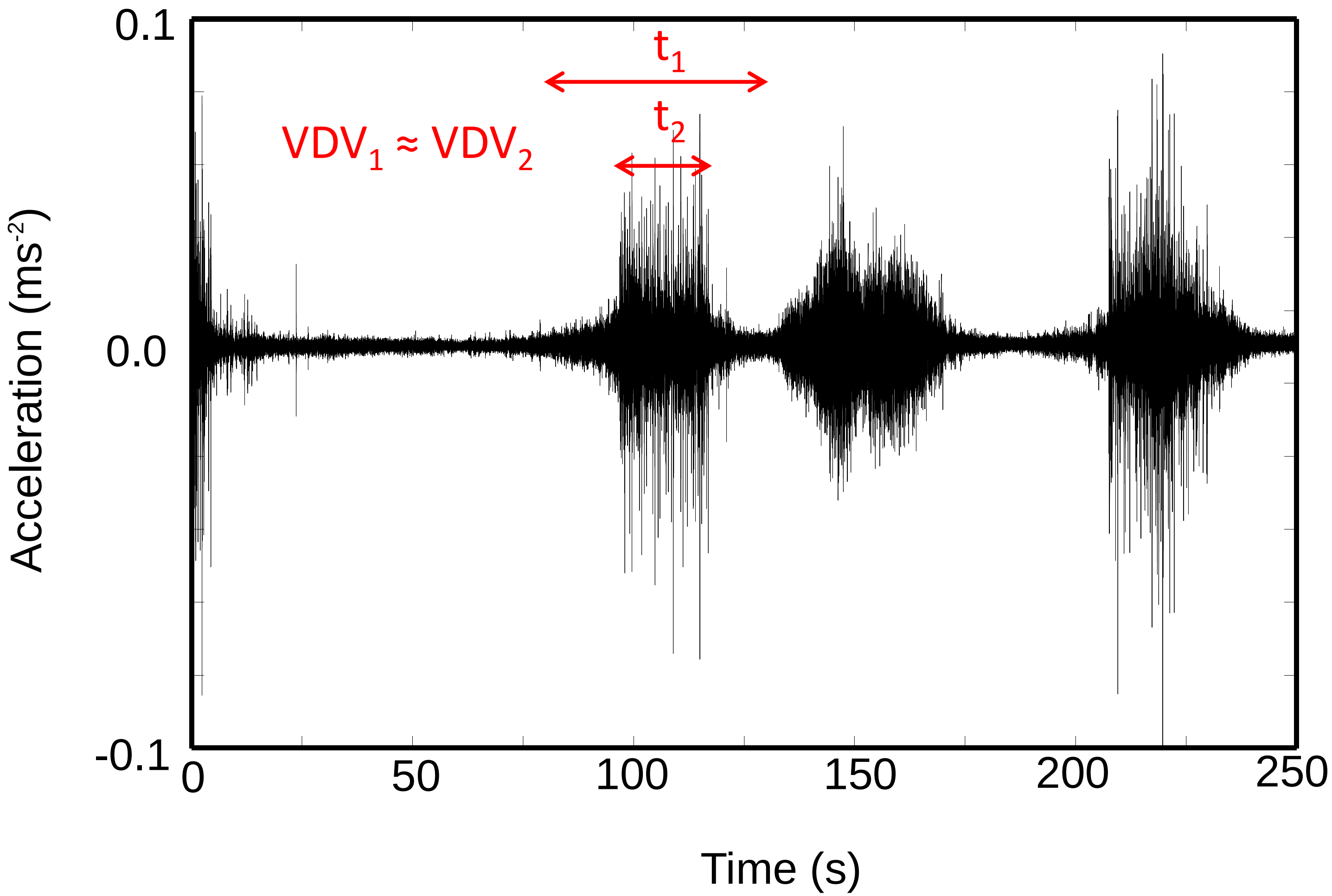
Evaluation – dose method

$$\text{root-mean-quad (r.m.q.)} = \left[\cancel{\frac{1}{T}} \int_{t=0}^{t=T} a_w^{\,4}(t)\,dt \right]^{\frac{1}{4}}$$

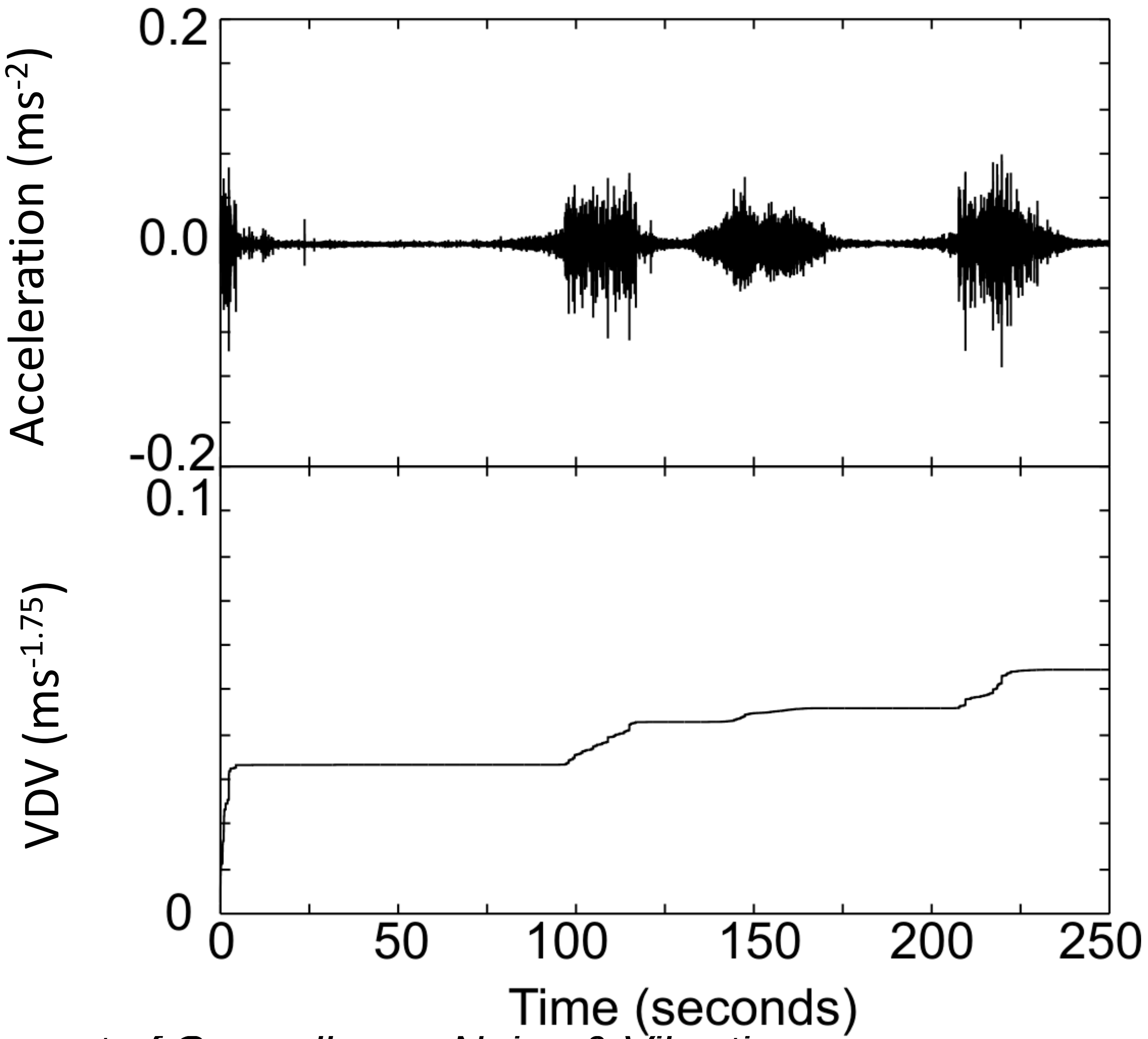
$$\text{vibration dose value (VDV)} = \left[\int_{t=0}^{t=T} a_w^{\,4}(t)\,dt \right]^{\frac{1}{4}}$$

Vibration dose value

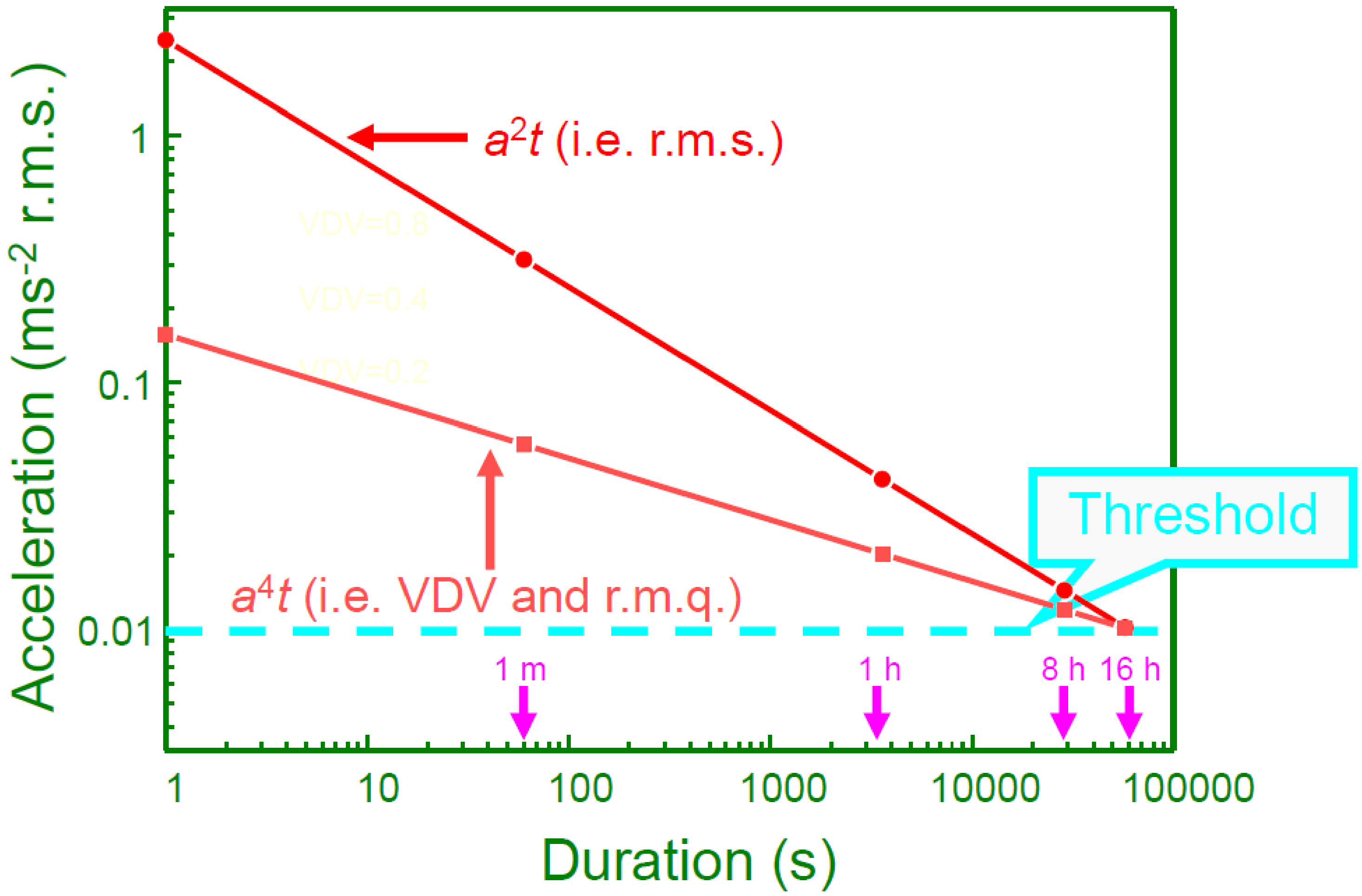
For VDV, the measurement period is not critical



Cumulative VDV over the passage of 3 trains



a^2t (r.m.s.) and a^4t (VDV) time-dependencies



VDV

- A practical solution to the complex problem of assigning a value to represent relative severity of vibration
- Allows for the influence of magnitude, frequency, duration and direction
- Forms the basis of assessments of acceptability of building vibration in BS 6472-1 (2008)

Vibration assessment

Assessment predicts the outcomes of vibration exposure:

- type of human response
- severity of human response
- probability of human response
- judgements of acceptability
- consequences

Vibration assessment

- Criteria for assessing vibration may be based on:
  - Perception
  - Annoyance
  - Disturbance
- Acceptability may depend on the absolute value or the change
- Depends on situation
- Limits can change over time - what is acceptable today may not be acceptable tomorrow.

Assessment: British Standard BS 6472-1 (2008)

VDV ($m.s^{-1.75}$) at which adverse comment might occur			
Residential buildings	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
day-time	**0.2** - 0.4	0.4 - 0.8	0.8 - 1.6
night-time	0.1 - 0.2	0.2 - 0.4	0.4 - 0.8

16 h @ 0.01 ms^{-2} r.m.s. (perception threshold)

Assessment: British Standard BS 6472-1 (2008)

VDV ($m.s^{-1.75}$) at which adverse comment might occur			
Residential buildings	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
day-time	0.2 - 0.4	0.4 - 0.8	0.8 - 1.6
night-time	0.1 - 0.2	0.2 - 0.4	0.4 - 0.8

Offices: 2 x day-time VDV, Workshops: 4 x day-time VDV

Assessment: British Standard BS 6472-1 (2008)

VDV ($m.s^{-1.75}$) at which adverse comment might occur			
Residential buildings	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
day-time	0.2 - 0.4	0.4 - 0.8	0.8 - 1.6
night-time	0.1 - 0.2	0.2 - 0.4	0.4 - 0.8

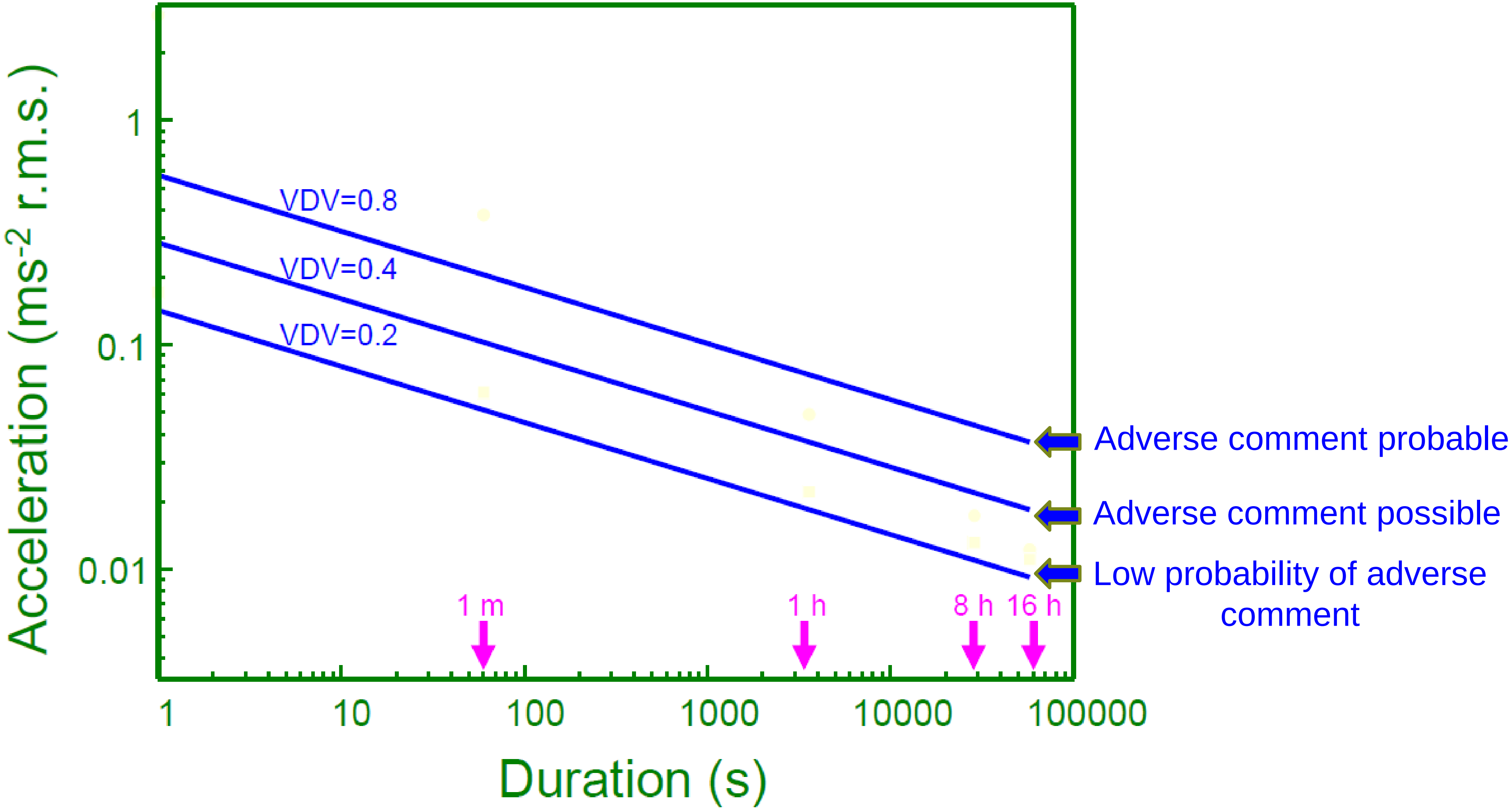
Lowest Observed Adverse Effect Level –
health and quality of life impact assessment

Assessment: British Standard BS 6472-1 (2008)

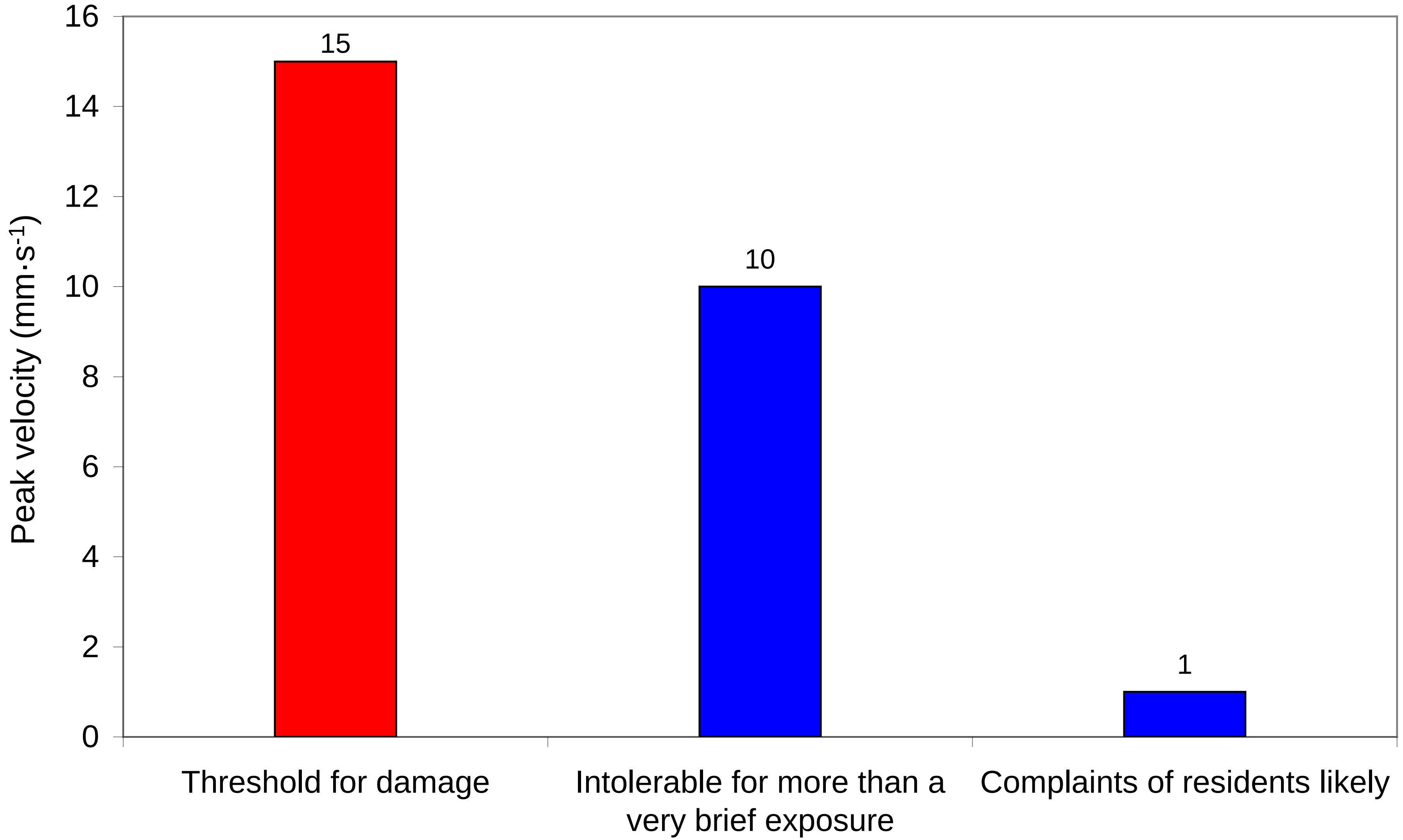
VDV ($m.s^{-1.75}$) at which adverse comment might occur			
Residential buildings	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
day-time	0.2 - 0.4	0.4 - 0.8	0.8 - 1.6
night-time	0.1 - 0.2	0.2 - 0.4	0.4 - 0.8

Significant Observed Adverse Effect Level – health and quality of life impact assessment

Effect of duration



Guidance in BS 5228:2



Field studies

Woodroof, H.J. and Griffin, M.J. (1987)

- Social survey and 24-h measurements in 52 dwellings in Scotland
- 35% of residents within 100 m of the railway notice the vibration
- Several of 90 evaluation measures investigated were correlated with vibration annoyance
- The number of trains produced the highest correlation indicating that annoyance was influenced not only by perception of vibration

Field studies

Defra/University of Salford (2011)

- Social survey involving 1431 residents and 24-h vibration measurements in dwellings near railways and at construction sites in England
- Exposure-response relationships were determined with various vibration evaluation measures including:
  r.m.s., r.m.q., VDV, peak acceleration, L_{max}, L_{eq}, L_E
- Most of the evaluation measures were significantly correlated with annoyance
- There were no differences between the significances of correlations with the different evaluation methods
- No evaluation method was identified as providing better predictions of vibration annoyance

Summary: evaluation and assessment with respect to human response

Evaluation:

- BS 6472-1: building vibration is evaluated using VDV by applying weightings to acceleration for frequency, duration and direction
- BS 5228-2: Building vibration is evaluated with respect to human response using peak velocity. The standard also refers to VDV

Assessment:

- BS 6472-1: vibration is assessed according to various VDV criteria to predict probability of adverse comment
- BS 5228-2: vibration is assessed according to peak velocity criteria to predict probability of complaints. The standard also refers to VDV assessment criteria in BS 6472-1

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