The impact of vibration on comfort and bodily stress while cycling

Centre for Transport and Society Winter conference and Universities' Transport Study Group
6th – 8th January 2014

John Parkin
John.parkin@uwe.ac.uk
Professor of Transport Engineering, Centre for Transport & Society
Eugénie Sainte Cluque
London South Bank University

Centre for Transport & Society

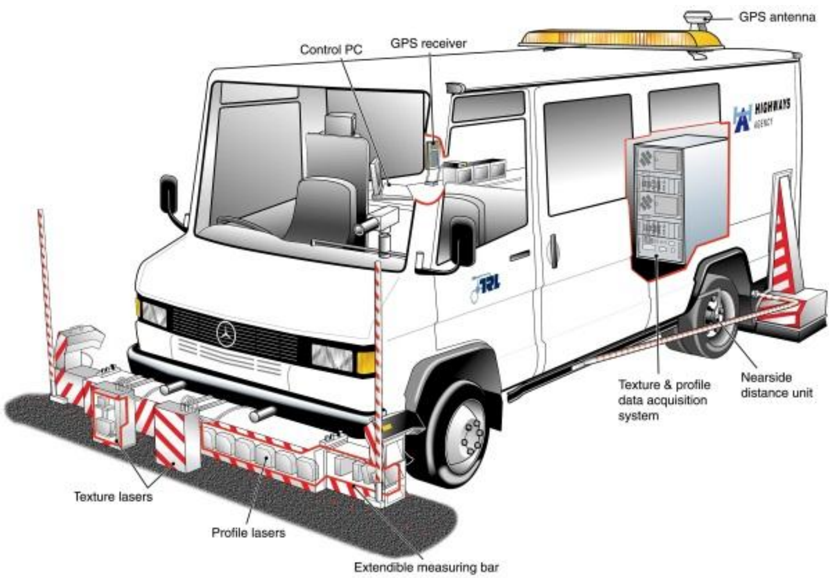
University of the West of England
BRISTOL

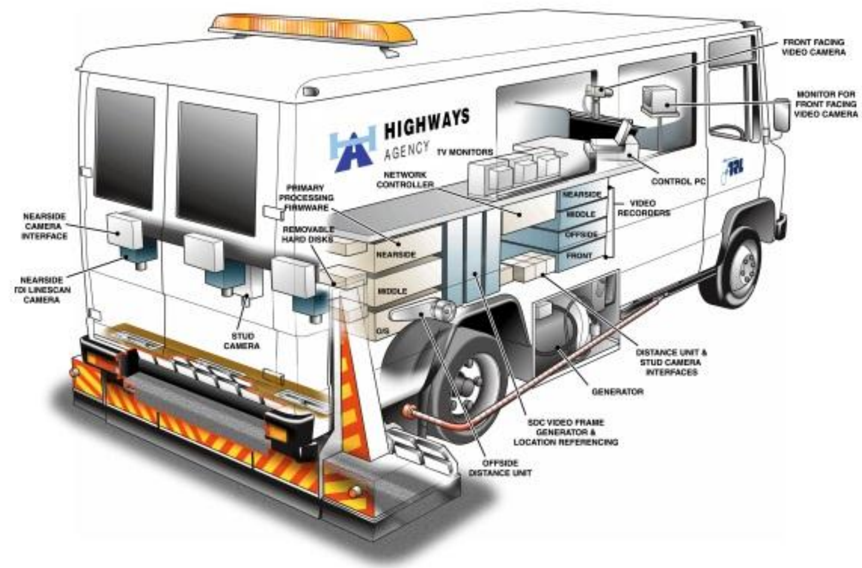
bettertogether

Overview

1. Measuring road surfaces
2. Standards for vibration exposure
3. Survey of cycle users
4. Fieldwork
5. Results
6. Future directions

1 Measuring road surfaces





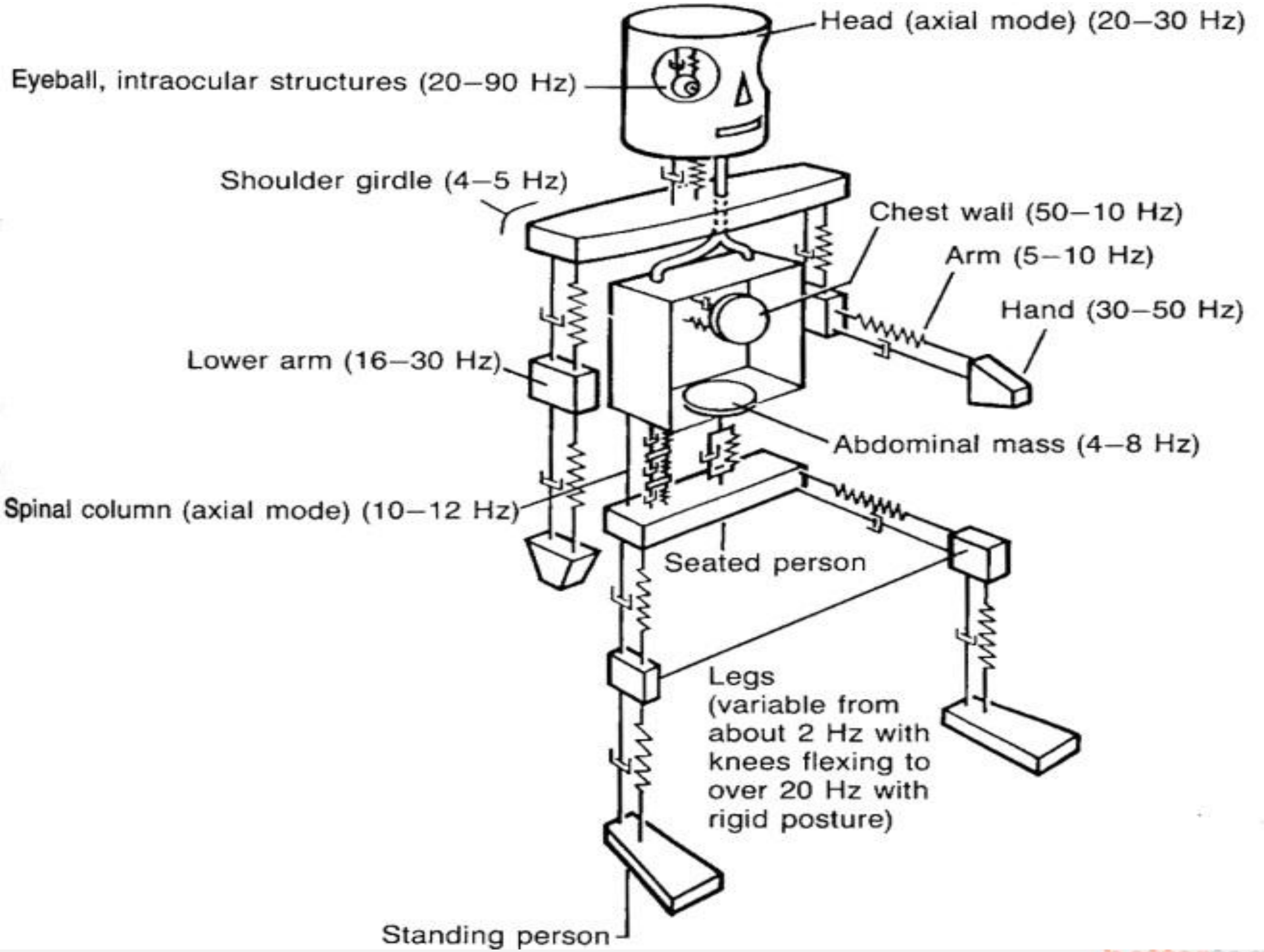
Surface Condition Assessment for the National NEtwork of Roads (SCANNER): Schematic of survey vehicle

Thresholds for road defect types

Defect	Investigation threshold	Maintenance threshold
Rutting	10mm 12mm for B roads	20mm 25mm for B roads
3m Longitudinal profile variance	$4mm^2$	$10mm^2$
10m Longitudinal profile variance	$21mm^2$	$56mm^2$
Whole carriageway cracking intensity	0.15%	2%
Wheel track cracking intensity	0.50%	5%
Texture	0.6mm	0.3mm

Road Condition Index from SCANNER Data

Defect	Importance factor	Reliability factor	Combined factor	Max. score
Rutting	0.9	1.00	0.9	90
3m Longitudinal profile variance	0.8	1.00	0.8	80
10m Longitudinal profile variance	0.6	1.00	0.6	60
Whole carriageway cracking intensity	0.9	0.55	0.5	50
Wheel track cracking intensity	0.9	0.44	0.4	40
Texture	0.5	1.00	0.5	50
			Maximum total RCI score	370


Head (axial mode) (20–30 Hz)
Eyeball, intraocular structures (20–90 Hz)
Shoulder girdle (4–5 Hz)
Chest wall (50–10 Hz)
Arm (5–10 Hz)
Hand (30–50 Hz)
Lower arm (16–30 Hz)
Abdominal mass (4–8 Hz)
Spinal column (axial mode) (10–12 Hz)
Seated person
Legs
(variable from
about 2 Hz with
knees flexing to
over 20 Hz with
rigid posture)
Standing person

2 Standards for vibration exposure

Vibration Dose Value (VDV, $m/s^{1.75}$) based on root mean quad (r.m.q.)

$$VDV = \left\{\int_0^T [a_w(t)]^4 . dt\right\}^{0.25}$$

$a_w(t)$ = instantaneous frequency weighted acceleration

T = duration of measurement.

Superior to root mean square (r.m.s.) which underestimates peak values

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t). dt\right]^{0.5}$$

VDV represents a cumulative value, r.m.s. represents an average value.

(Source: BS ISO 2631-1:1997
Human exposure to whole body vibration)

European Directive 2002/44/EC11 Exposure in the workplace

In an eight hour period, exposure defined as:

$$A_i(8) = k_i . a_{wi} \sqrt{\frac{T}{T_o}} \qquad VDV_i(8) = k . VDV_{wi} \sqrt[4]{\frac{T}{T_0}}$$

Axis i is x, y or z

k_i is a factor for each axis.

T is the duration of exposure

T_0 is the reference duration of 8 hours.

For whole-body vibration, the highest value the $A_i(8)$ and $VDV_i(8)$ is the daily exposure dose.

(Source: European Directive 2002/44/EC11 Exposure in the workplace)

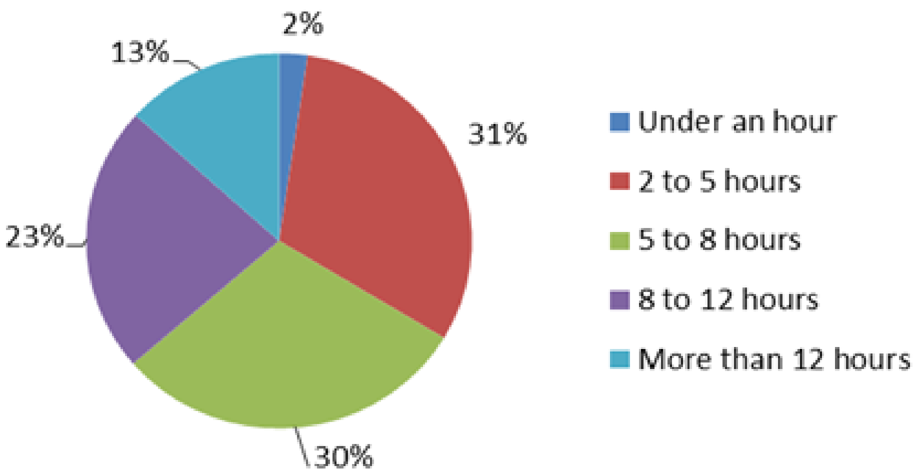
	Exposure Action Value	Exposure Limit Value
A(8)	0.5 m/s^2	1.15 m/s^2
VDV(8)	9.1 m/s$^{1.75}$	21 m/s$^{1.75}$

bettertogether

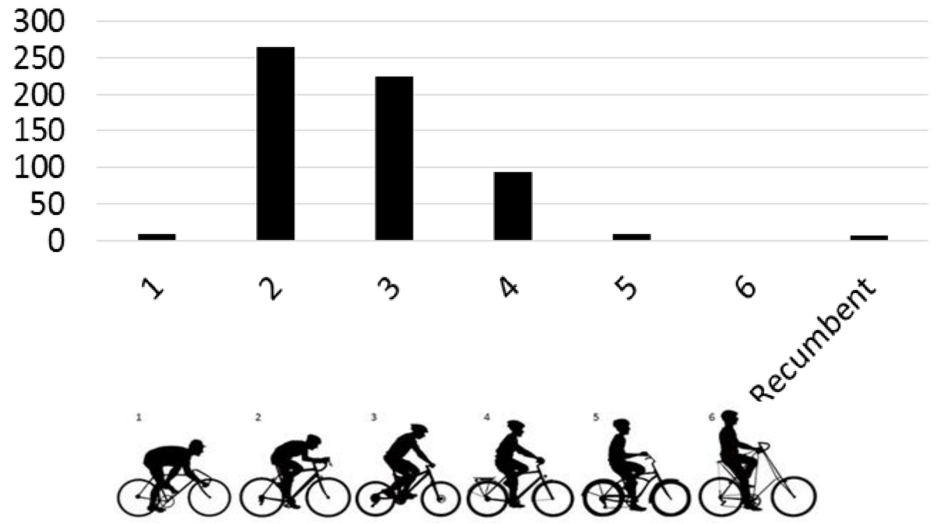
3 Survey of cycle users

- N=644
- Male=79%
- Main mode of transport = 51%
- Aged 46-64 = 51%
- Aged 65+ = 25%

Percentage by hour bands of cycling activity per week



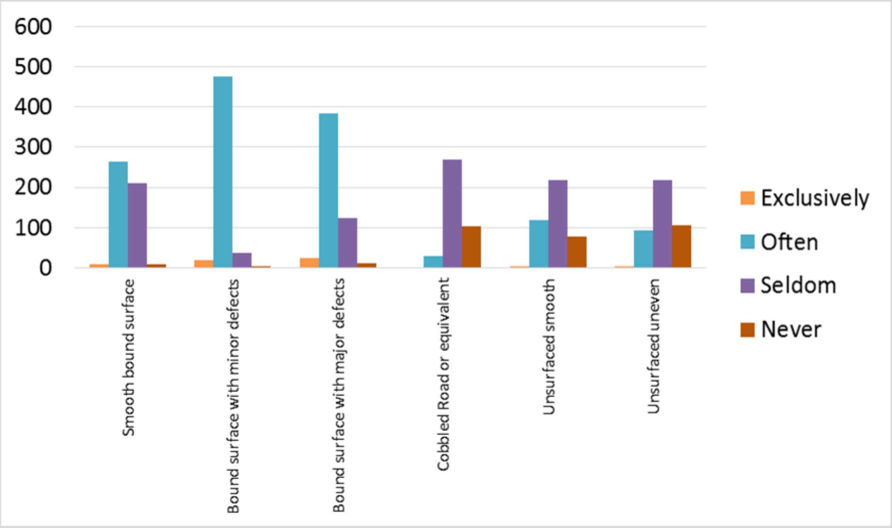
Riding position



Bicycle materials and degree of suspension

	None	Fork	Seat Post	Total
Steel	230	25	29	284
Aluminium	197	63	46	306
Titanium	29	1	0	30
Carbon fibre	50	12	4	66
Unknown	23	9	11	43
Total	529	110	90	729

Types of surface and extent of use



Discomfort and pains reported during and after cycling

	During cycling	After cycling	Total
Hand/arm numbness	420	130	550
White fingers	100	40	140
Trapped nerves: hand/arm	38	22	60
Elbow pain	47	38	85
Head Ache	32	40	72
Knee pain	142	125	267
Upper back pain	65	42	107
Lower back pain	136	105	241
Trapped nerves: legs	10	9	19
Total	990	551	

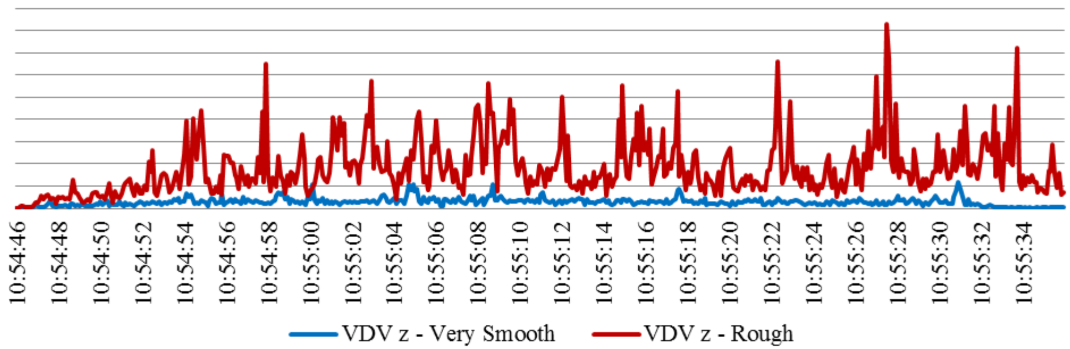
4 Fieldwork

Bitumen macadam surface with fine grade aggregate. Pitshanger Park, W5 London 274.5 m	Very smooth	(no photograph available)
Bitumen macadam surface with medium grade aggregate. Eaton Rise, W5 London 612 m	Smooth	
Bitumen macadam surface of either fine or medium grade aggregate with minor defects such as re-instatements and small surface defects. Woodfield Road, W5 London 419 m	Medium	
Bitumen macadam surface of either fine or medium grade aggregate with major defects such as medium and large pot holes and depressions. Pitshanger Park, London, W5 London 273.7 m	Rough	

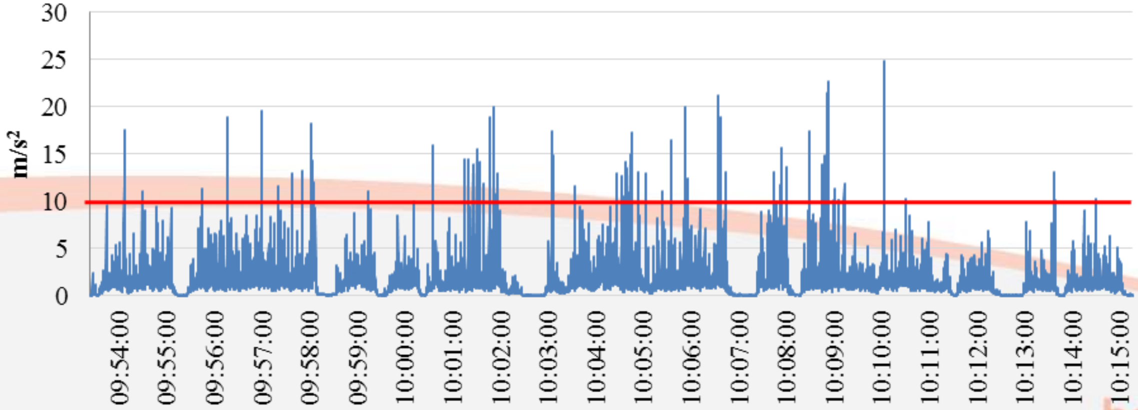
	Parameters
Equipment	Svan958 + Dytran3233A 28g
Axis	vertical
Weighing	w_k
Measurements	acceleration amplitude expressed as VDV ($m/s^{1.75}$)
	acceleration amplitude expressed as r.m.s (m/s^2)
Frequency range	0.5 Hz to 20 kHz
Frequency bands	1/3 octaves
Integration	100 ms
Range	300 m/s^2
Placement of the accelerometer	Rear axle
	Seat-post closest to the saddle possible
	saddle

5 Results

VDV of 100ms integrations over a 50 second measurement at seat post for steel framed bicycle with suspension seat post for very smooth and rough roads

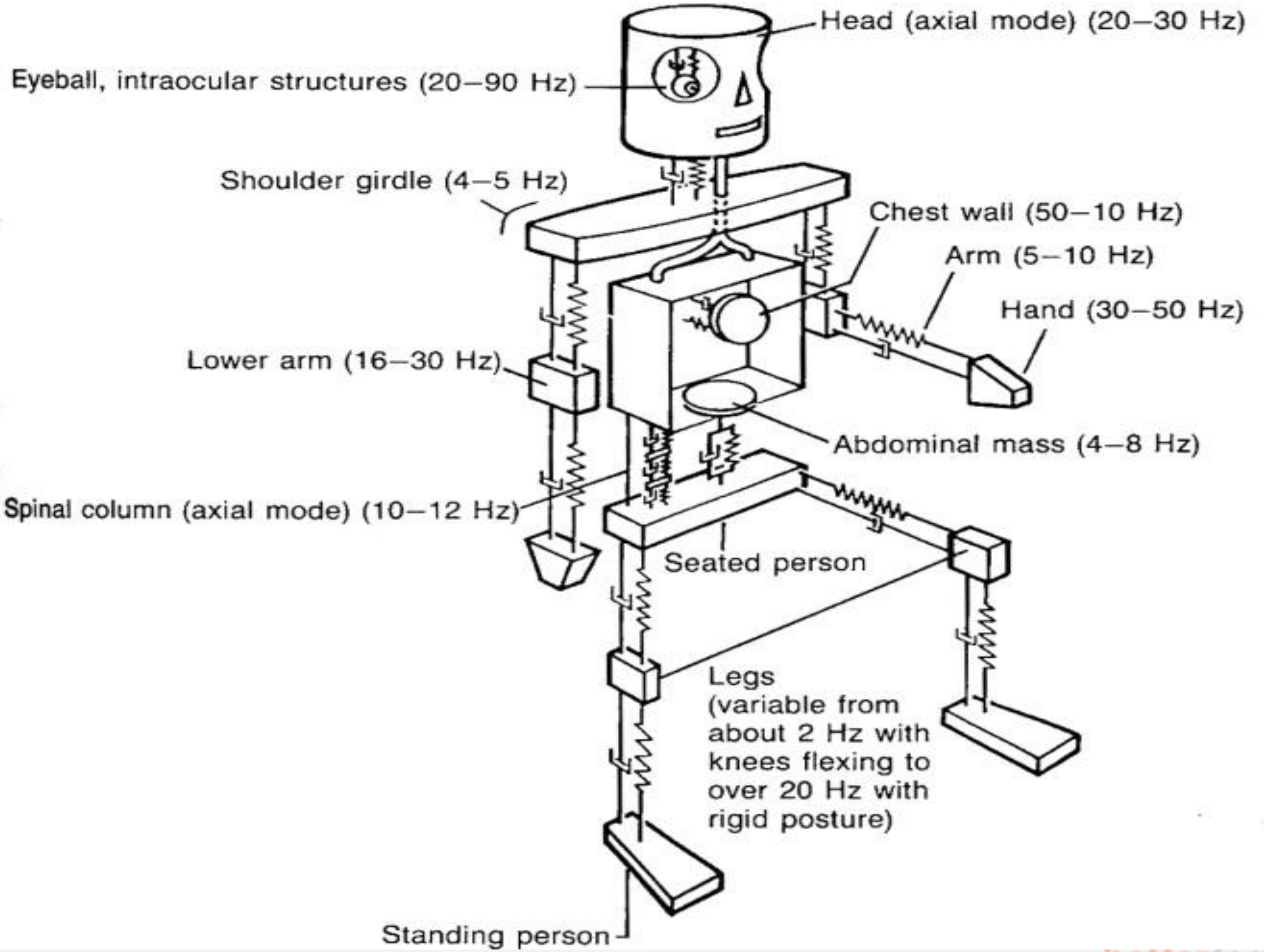


RMS at seat post for steel framed bicycle with suspension seat post for journey to work (10m/s² known to damage health)

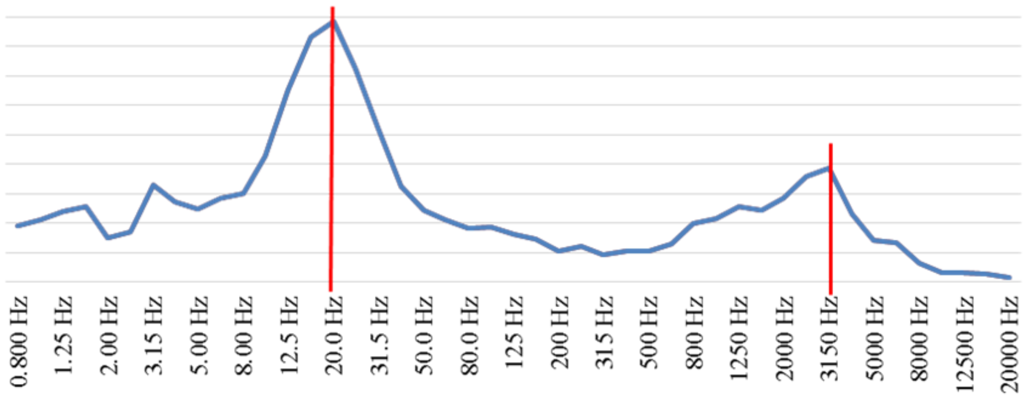


Summary of possible sources of impact on VDV

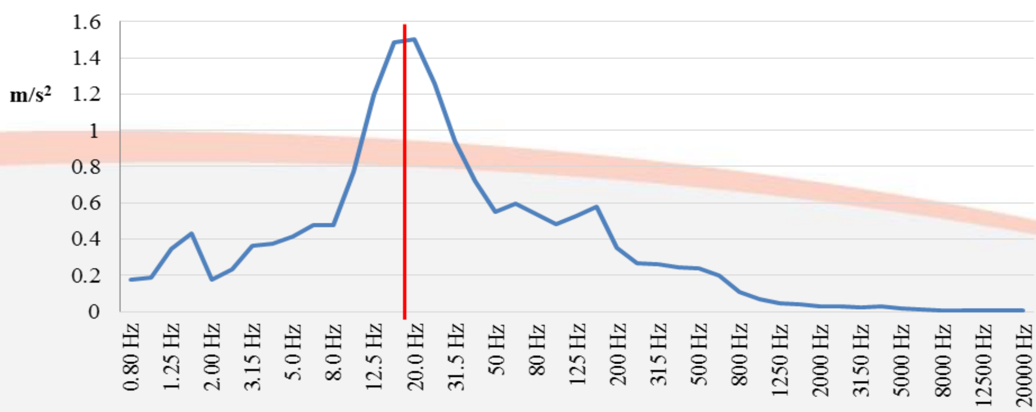
Variable	Comment
Road surface condition	Greatest source of variation in VDV
Variability in road condition (smooth to rough)	Possible contribution to VDV
Higher speed	Higher VDV up to a threshold, reducing thereafter
Measurement position on bicycle	Higher VDV at back wheel than seat post
Uphill cycling side-to-side swaying motion	May impact on VDV in the vertical axis
Bicycle material and geometry	Impact on VDV in different ways
Seat post suspension	Reduces amount of VDV


Head (axial mode) (20–30 Hz)
Eyeball, intraocular structures (20–90 Hz)
Shoulder girdle (4–5 Hz)
Chest wall (50–10 Hz)
Arm (5–10 Hz)
Hand (30–50 Hz)
Lower arm (16–30 Hz)
Abdominal mass (4–8 Hz)
Spinal column (axial mode) (10–12 Hz)
Seated person
Legs
(variable from
about 2 Hz with
knees flexing to
over 20 Hz with
rigid posture)
Standing person

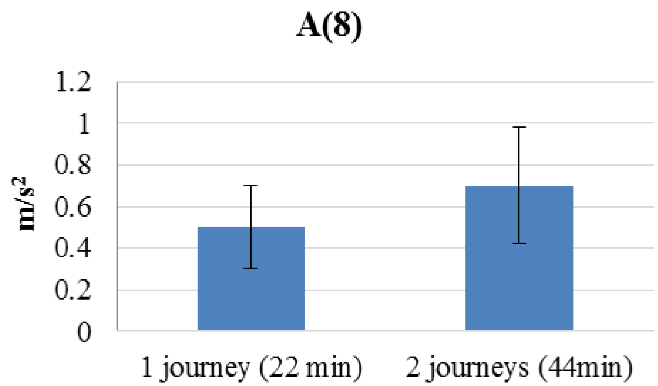
Seat post r.m.s per third octave frequency spectrum steel framed bicycle with suspension seat-post and gel saddle

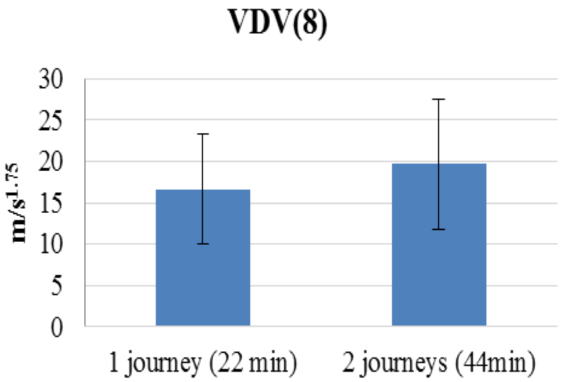


Saddle r.m.s per third octave frequency spectrum steel framed bicycle with suspension post and gel saddle



Daily vibration dose estimated at the saddle expressed in terms of A(8) (r.m.s.) and VDV(8) for one and two journeys using Bicycle One (bars represent 95% confidence interval)





Comparison of A(8) (m/s^2) of bicycle with agricultural tractor use

	Daily exposure range		
Machine	**X (fore and aft)**	**Y (side-to-side)**	**Z (vertical)**
Agricultural tractor - ploughing	0.3 to 0.6	0.5 to 0.9	0.3 to 0.5
Agricultural tractor - cultivating	0.3 to 0.9	0.5 to 1.4	0.3 to 0.7
Agricultural tractor - spraying	0.3 to 0.5	0.4 to 0.8	0.3 to 0.4
Agricultural tractor - trailer work	0.5 to 1.1	0.4 to 0.9	0.3 to 0.5
Bicycle for 44 minutes	0.6	0.5	0.7

6 Future directions

- Real world important, but repeatability a challenge
- Consider all points of vibration entry
- Consider variety of bicycle types and riding position
- Consider impacts on different parts of the anatomy

Interfaces of interest for vibration propagation