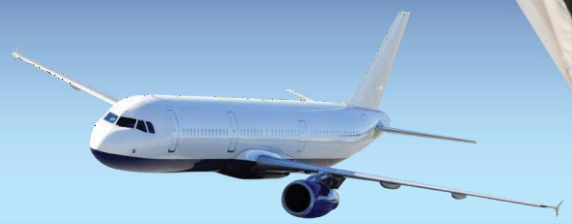
GIVE YOUR CAREER WINGS WITH A

POSTGRADUATE CERTIFICATE IN

AVIATION MEDICINE



17 February 2025

Lecture: # Noise and Vibration

presented

by: Dr. Frans Johannes Cronjé,

MBChB, MSc Aerospace Medicine, PGDOccMed, Fellow EHM (Duke), BCN

Courtesy of Dr Derek Jacobs

Dr. Frans Johannes Cronjé is a seasoned Aviation and Aerospace Medicine Specialist, registered by the National Health Regulatory Authority in Bahrain. He currently serves at King Hamad American Mission Hospital, where he runs the Aviation Medicine Clinic. With over 30 years of experience in clinical practice, research, and academia, Dr. Cronjé has made significant contributions to aviation, diving, and hyperbaric medicine. His qualifications include an MBChB, BSc(Hons), MSc in Aerospace Medicine, and a Postgraduate Diploma in Occupational Medicine – all achieved cum laude.

Dr. Cronjé has held senior roles, including Medical Director and Senior Researcher, and has worked with multiple Civil Aviation Authorities, including Bahrain, the UAE, South Africa, and Mauritius. His leadership extends to positions such as President of the Southern African Undersea and Hyperbaric Medical Association and Founder of the Divers Alert Network Southern Africa. He is a Life Member of SAAsMA.

A prolific researcher, Dr. Cronjé has authored numerous publications and contributed to major textbooks on hyperbaric and diving medicine. He is actively engaged in innovative research, combining hyperbaric oxygen therapy with neurofeedback. His expertise spans a range of fields, including vestibular rehabilitation, tinnitus management, and occupational health, emphasizing his dedication to improving medical care in high-risk environments.

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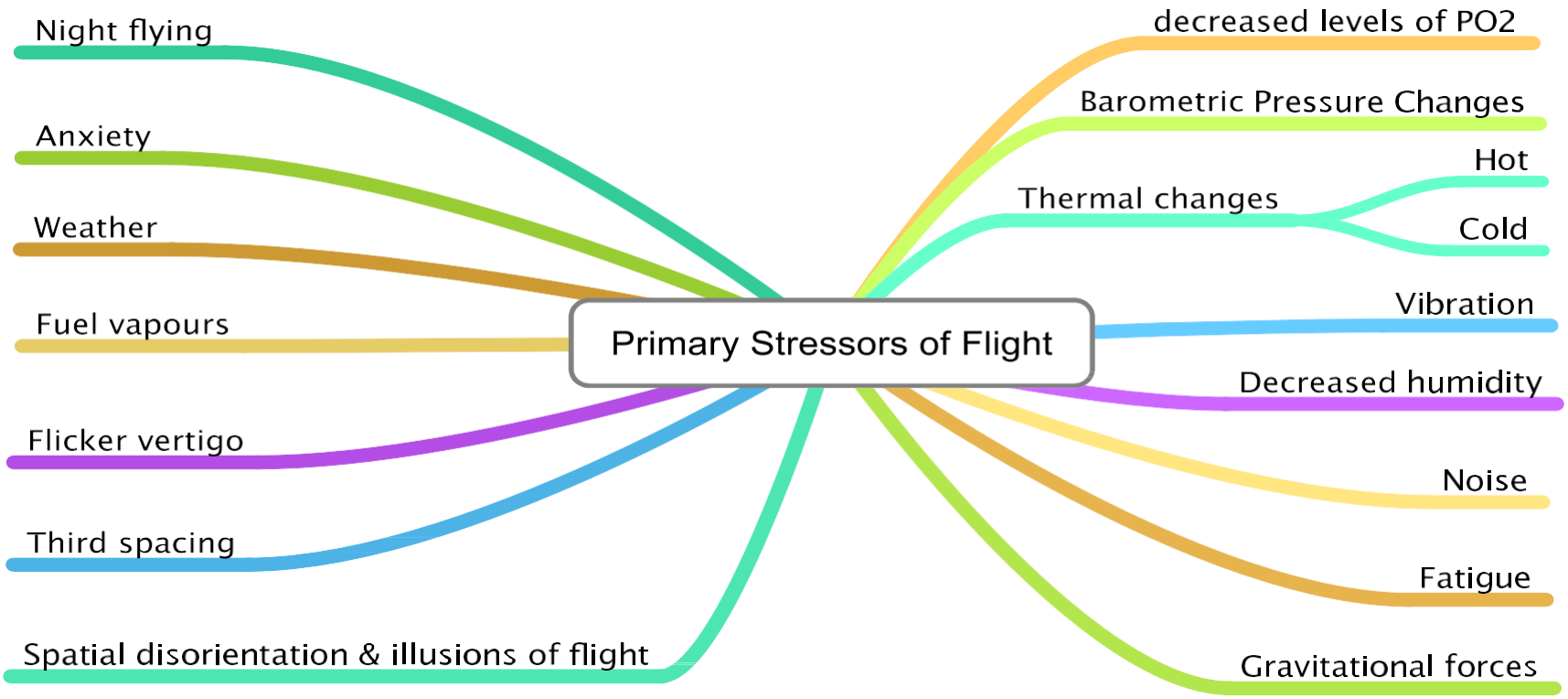
NOISE & VIBRATION(2)



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NOISE & VIBRATION(3)

POSTGRADUATE CERTIFICATE IN AVIATION MEDICINE:

NOISE & VIBRATION(4)

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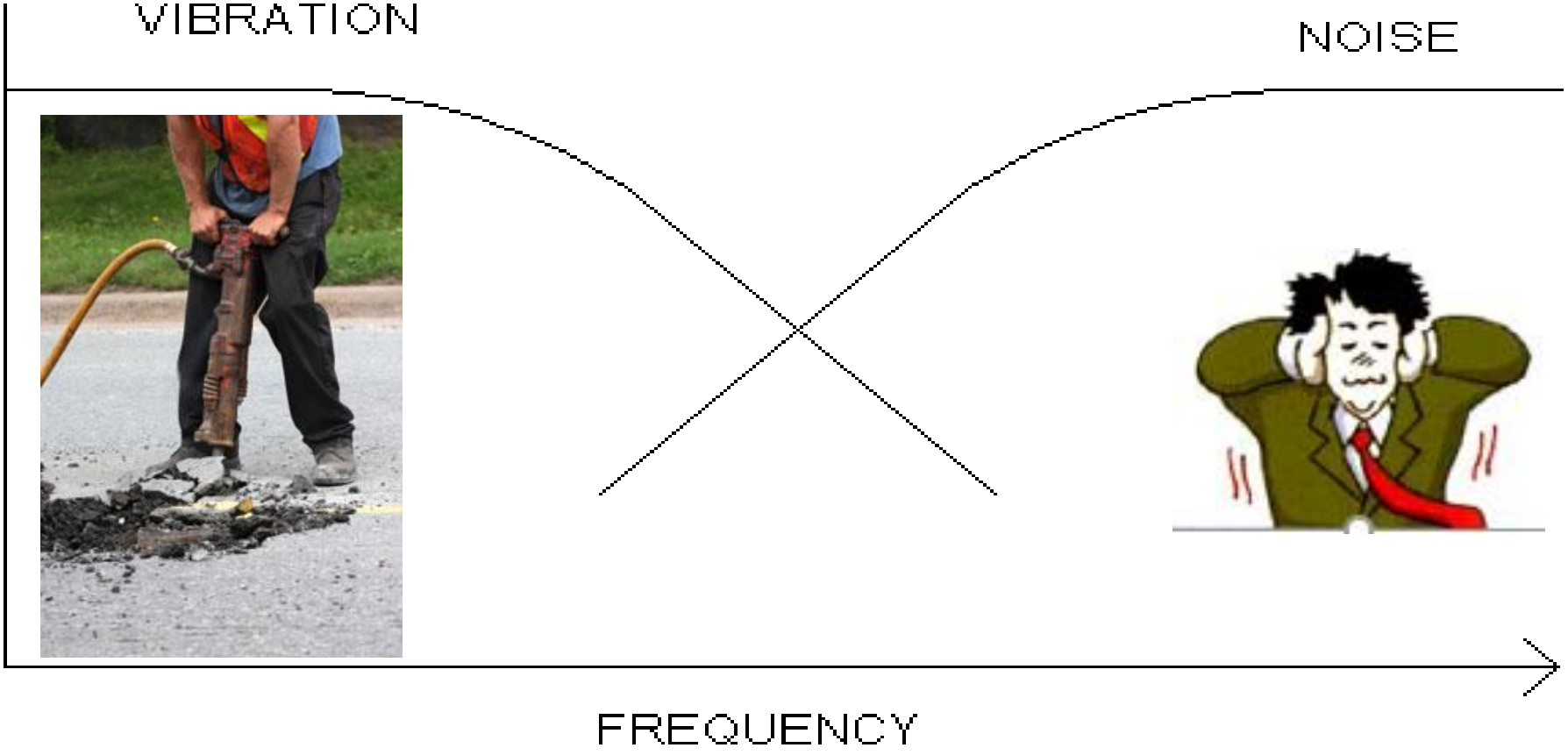


Vibration:

Acceleration is used as the fundamental measure of vibration.

Vibration is described relative to its effects on man in terms of:

Amplitude(intensity)(maximum displacement)

Direction

Frequency (cycles per second (Hertz, Hz)

Effects of Vibration:

Depends on frequency range & exposure conditions

Can affect the entire body - physical complaints include:

- Hyperventilation, dyspnoea & chest pain
- ↑ arterial blood pressure and heart rate
- Headache
- Epigastric discomfort, testicular pain

Routine vibration exposure in an aircraft is below injury and interference levels.

Effects of Vibration (continued):

Affects task performance:

Interferes with sensory and motor tasks

Difficulties:

- reading instruments &
- in performing visual searches
- increased errors in motor performance
- impaired quality of speech
- generalized fatigue

Frequency(Hz) range:

Hertz: 1 Hz = 1 cycle/second

0-20 Hz

- This is range of interest in aviation
- It causes harmful physiological effects

Above 20 Hz

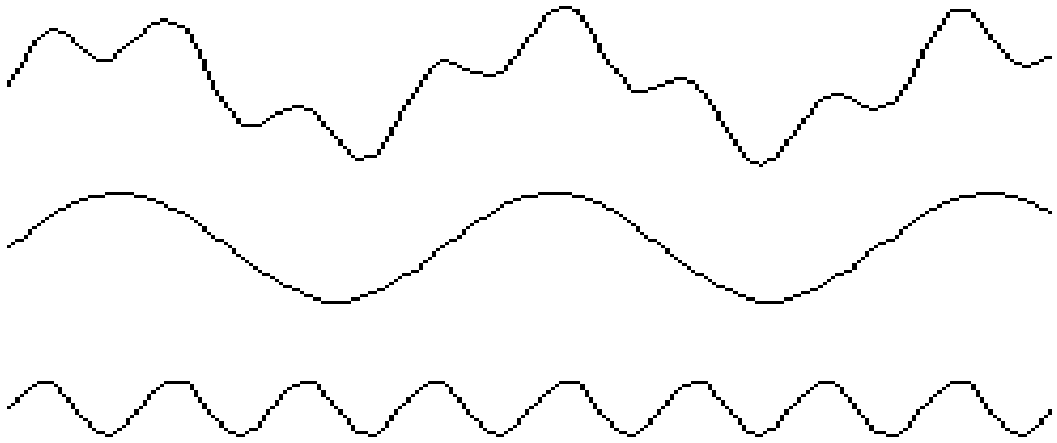
- causes fatigue and discomfort
- Is annoying but not harmful

Frequency composition:

Sinusoidal (rare in aviation, e.g. can be caused by helicopter blades)

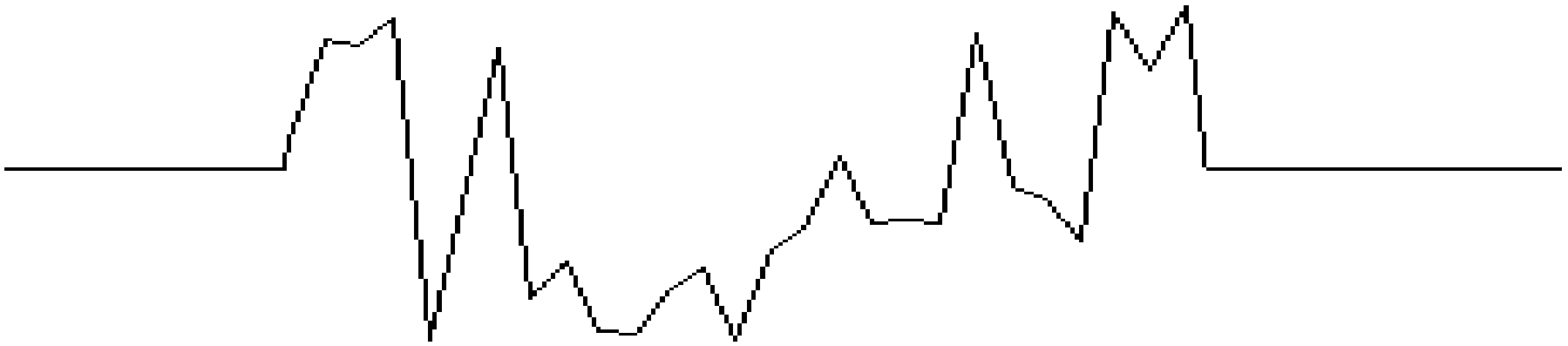
Frequency composition:

Compound Harmonic (more common in aviation, multiple component frequencies & amplitudes)



Frequency composition (continued):

Random (e.g. periodic disturbances such as **turbulence**)



Sources of Vibration:

- Engines
- Rotor(s)
- Gearbox
- Atmospheric turbulence
  - Clear air turbulence (CAT)
  - Storms
  - Low altitude high speed flight
  - Firing of onboard Weapon e.g. machine guns

Measure of Vibration: Newton (N):

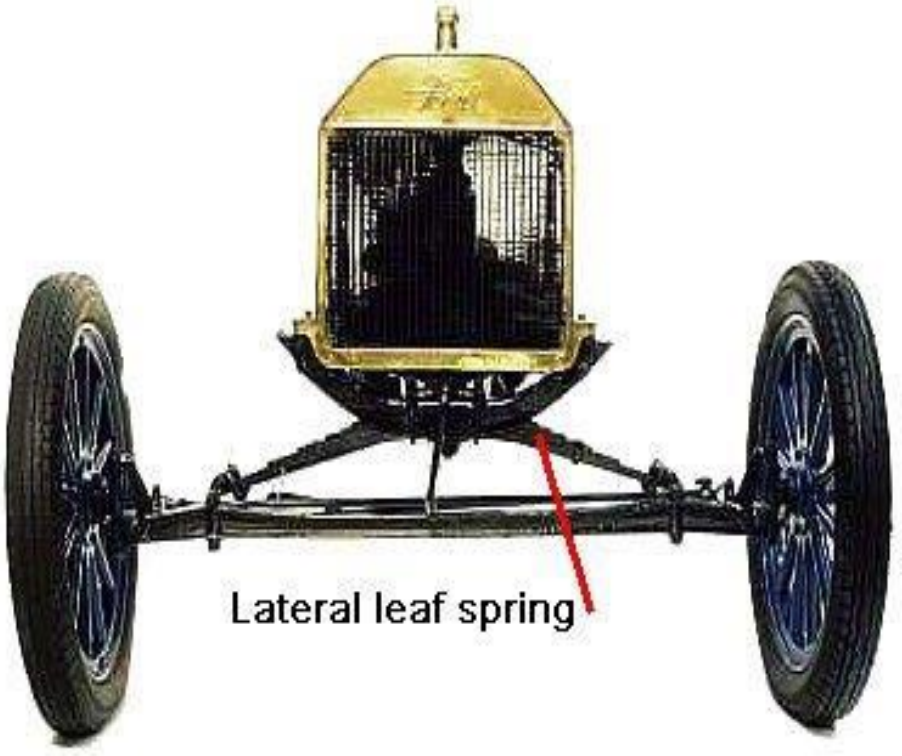
- *Force = Mass x Acceleration* (Newton)
- g-force (force caused by earth's gravity(acceleration))
- Expressed as "+" or "– "g (in the x, y and z axis)
- 1 g = 9,8 m/s/s
- Some sources of Vibration can cause acceleration of up to 98 m/s/s
- A/c occupants experience forces up to 10x g-force

Gravity (g) vs Universal acceleration (G)

- **G-force = G.m1.m2/r²** (where G is the universal constant)
  - calculates the gravitational force between two bodies
  - universal constant remains the same throughout the universe
  - is independent of the masses of the objects
  - is an empirical physical constant (6.673×10^{-11} N)
- **g-force (g): gravity**
  - is an object's acceleration relative to free-fall on Earth
  - is 9.8 m/s/s at sea level
  - 1 g is the force of gravity at the Earth's surface

Systemic response to vibration:

- The system(body) has 3 characteristics that determine its response namely: MASS, ELASTICITY and DAMPING
- A motorcar wheel has the 3 same 3 factors, that in combination determines its response to a source of vibration, ie a corrugated road:
    - damping (shock- absorber),
    - elasticity(coil/leaf spring), &
    - mass(weight)



Resonance

- Each system has a response (maximum displacement) at a unique ***resonant frequency*** which depends on its mass, elasticity & damping
- Human body has rigid masses (pelvis,upper body) & elastic structures (lumbar spine)
- It can behave like 2 weights on a spring
- It resonates in a complex fashion

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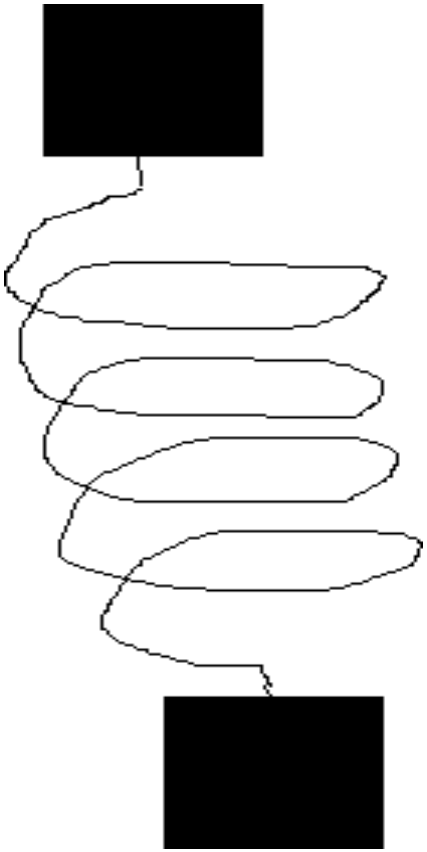
NOISE & VIBRATION(17)



Damping factor:

- How fast the amplitude of oscillation of a part of the body fades, when the vibratory stimulus is gone
- The body acts like an assembly of masses, springs and dampers coupled loosely together, with each sub-unit having its own mass, elasticity, damping & resonant frequency ➔ <u>complex response</u>

Effects of Vibration:

- < 1 Hz – motion sickness
- 1-2 Hz – soporific effects (water bed)
- 2-6 Hz – difficulty controlling the position of an outstretched hand - ‘heavy’
- 3-4 Hz – progressive fatigue & discomfort
- 5-8 Hz – speech & breathing is difficult

Effects of vibration (continues):

- 8-9 Hz – felt as “fluttering” (butterflies)
- 9-12 Hz – speech & visual difficulties
- 12-20 Hz – feels like exercise,
    - increased breathing effort
    - chest pain & backache
- >20 Hz – usually associated with noise

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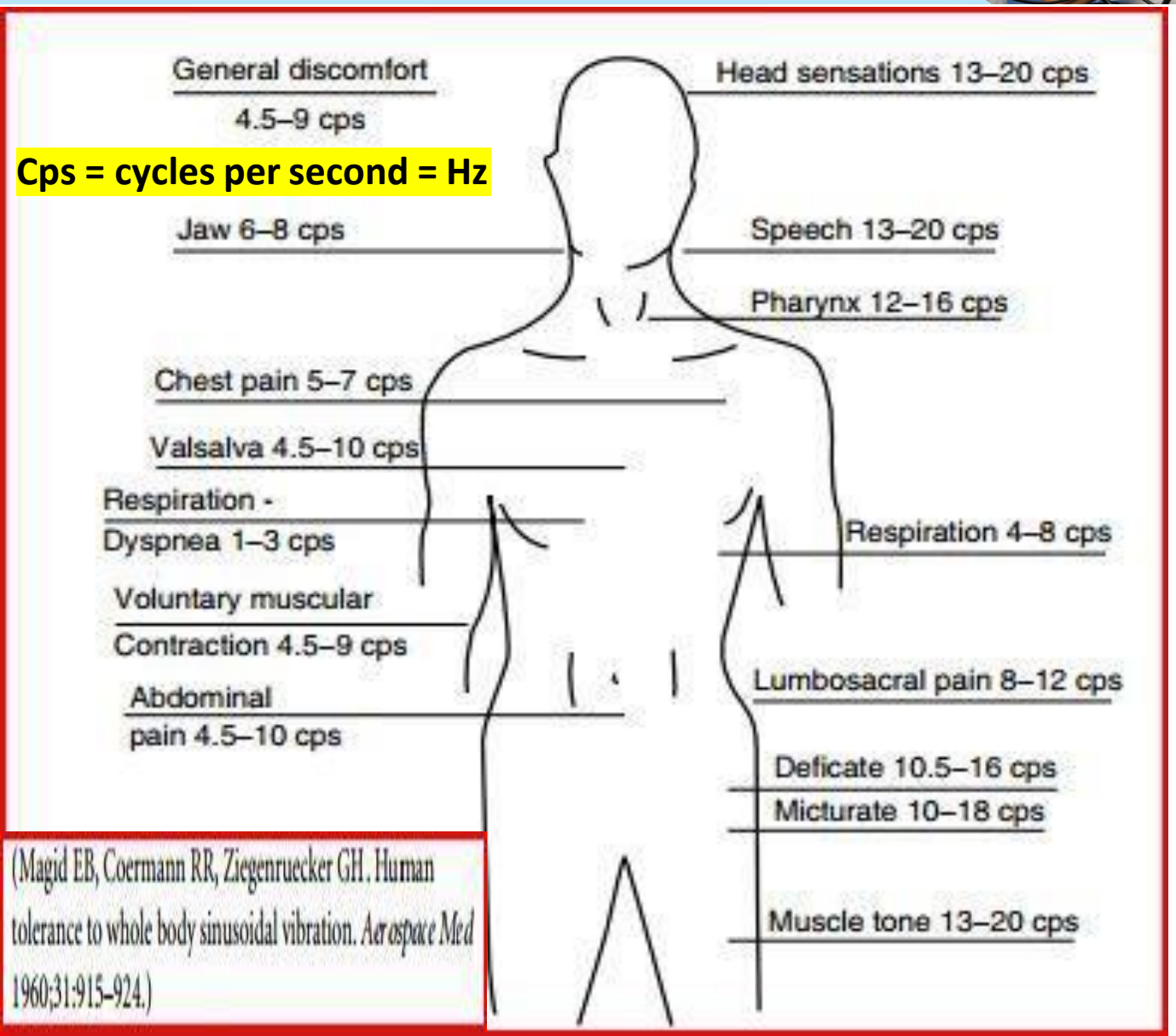
NOISE & VIBRATION(21)



(Magid EB, Coermann RR, Ziegenruecker GH. Human tolerance to whole body sinusoidal vibration. *Aerospace Med* 1960;31:915–924.)

First Major Body Resonance:

- 4-5 Hz: Greatest body resonance – shoulder girdle; also liver, diaphragm, mediastinum, abdominal wall.
- a 70 kg person has an apparent mass of 130 kg

Second Major Body Resonance:

- 12-15 Hz: Resonant vibration of the head is the principal effect
- Associated with axial compression of the torso modified by elastic properties of the spine (important during impact &/or ejection)

Effect on of Vibration on Performance:

- **Vision**:
  - above 4 Hz Visual Acuity is progressively impaired as ether of/or all of frequency, amplitude or acceleration increase
  - Tracking impaired between 1-30 Hz, the greatest decrement between 4-8 Hz
  - Two reflexes promote stability when the head is moving
    - The vestibulo-ocular reflex
    - The pursuit reflex

Effect of Vibration on Vision (continued):

- The pursuit reflex is mediated visually & uses error of visual fixation to generate eye movement
- The vestibulo-ocular reflex uses sensory information from the semi-circular canals to generate angular eye movements when the head is moving

Effect on Performance (continues):

- Speech:
  - Difficult if vibration severe
  - May be disrupted at low frequencies
- Hearing:
  - Above 20 Hz vibration is rarely found without noise
  - Above 20 Hz, noise and vibration may be produced by the same compression waves

Effect of vibration on Performance(cont):

- Touch and kinaesthetic senses:
  - Afferent signals sent to the CNS that normally result from normal movement is masked by the large amount of afferent information that is transmitted from the vibrated muscles & tendons
  - Position and velocity signals normally used for accurate tracking of limb position in rest and position during movement become ineffective.

Effect of Vibration on Performance(cont.)

- Cardiovascular:(= moderate exercise)
  - Tachycardia
  - Rise in cardiac output
  - Increased arterial pressure
  - Vasodilatation
  - Frequency near heart (60 -80Hz) rate can cause large beat to beat swings and bizarre changes in heart rate and ECG

Effect of Vibration on Performance(cont):

- Respiratory:
  - 1 to 10 Hz with amplitude > 0.5g can cause:
    - severe hyperventilation and hypocapnoea
    - < 0,1 g - speech & breathing OK

Effect of Vibration on Performance(cont):

Spinal and postural reflexes
(in standing position):

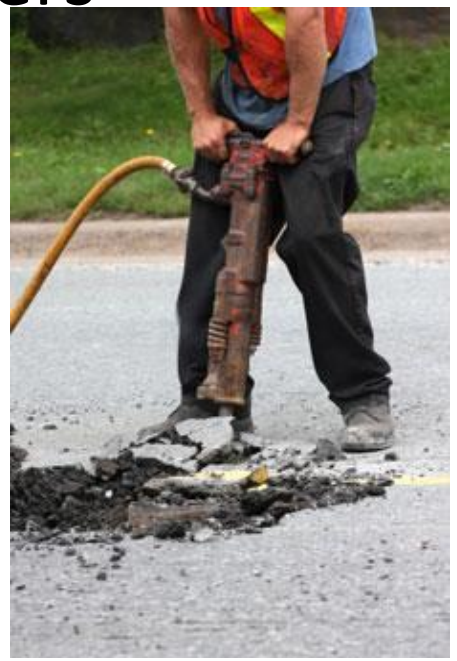
- A Perceived Increase in postural oscillation amplitude causes forward tilt in main posture position
- Spinal reflexes deeply depressed
- Trying to remain upright causes subject to lean backward to the point where s/he may fall over.

Pathology caused by Vibration

- Abdominal pain
- Chest pain
- Testicular pain
- Dyspnoea
- Difficult speech
- Anxiety
- Discomfort
- Muscle pain

Vibration Dose Value(VDV)

- VDV Formula used by engineers/designers
- A single figure for assessing vibration
- Integrates severity & duration
- OHS implications
  - Whole body vibration -- spinal disorders
  - Hand transmitted e.g. vibration white finger



When Vibration Stops:

Transient illusion of motion in the opposite direction

Prevention of Vibration Injury

- Avoid
- Re-engineer design prevent Flutter
- Dynamic vibration absorbers
- Isolation of aircrew seats
- Active vibration absorption
- Earthquake compensated buildings
  - eg San Francisco, Japan

•Prevention of Vibration (cont.)

- Cushions and springs – unfortunately not compatible with Ejection seats
- Hanging stretcher mounts OK for patient
- Strapping in with a head restraint
- Rigid restraints – impractical

Noise

- Noise and vibration may be produced by the same compression waves above 20 Hz
- Vibration above 20 Hz is rarely found without noise

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NOISE & VIBRATION(34)

Noise Exposure Without Hearing Protection Lead to Irreversible Hearing Loss:

Sound	Intensity (dBa)*	Time of Exposure
Whispering	20	No limit
Normal conversation	60	No limit
Car	70	No limit
Diesel truck	100	2 h
Jackhammer	100	2 h
Helicopter	105	1 h
Live rock music	90-130	30 min to 8 h
Propeller aircraft	120	7 min
Jet aircraft	140	Imminent hearing loss at any length of exposure

*dBa refers to noise levels measured by noise-monitoring equipment, similar to how they would be interpreted by the human ear

Types of Noise by duration:

- Continuous noise
  - sudden or gradual onset
  - long duration (> one second)

Examples:

- aircraft power-plant noise
- propeller noise
- pressurization system
- cabin air-conditioning

Occ Health & Safety Rules – max exposure allowed

- 85 dB for eight hours.

Types of Noise (cont.):

- **Impulse/Blast:**

  sudden onset and brief duration (< one second)

  usually exceed an intensity of 140 dB

Examples:

handgun, firecracker,

backfiring of a piston engine

sonic boom caused by breaking the sound barrier.

NB!! The eardrum may be ruptured by intense levels (140 dB) of impulse/blast noise.

Noise (continued):

- Sound pressure: Measured in Pascal (Pa)
- Sound Pressure Level (SPL): Measured in decibel (dB)
- The threshold of human hearing at 1 kHz is a sound pressure of about 20 micro Pascal = SPL of 0 dB
- Max sound pressure tolerated is 200 Pa = SPL of 140 dB (dynamic range, log scale)

Noise (continues):

Question?

If two sound sources with the same SPL of 70 dB each are placed side by side, what is their over-all SPL (OASPL)?

Noise (continues):

Answer = 73 dB

Doubling the sources = OASPL + 3 dB to individual SPL
(perceived as only being a little louder)

Four sources (doubling again):

OASPL = + 3 dB = 76 dB

(Confounding factors are: proximity to walls, wall covering, size of room, position in room, etc)

Noise (continues):

- **To 'double' the Sound Pressure Level:**
  You need an increase of about 10 db SPL to 'double' the perceived sound
- Doubling the wattage rating of an amplifier (eg 50 to 100W) = an increase of 3 db SPL
- You need 10 X more power to 'double' SPL
- A speaker with sensitivity of 70 db@1W/1m must increase 1W to 10W to get 80db, and needs an Increase to 100W to get 90 db SPL
- Sensitivity & efficiency of speakers helps

Noise Formulae: equivalent sound level (dBa) & time-weighted average(TWA):

$$L_{eq} = 10 \log \left[1/T \sum_{i=1}^{n} 10^{L_{Ai}/10} t_i \right]$$

$$TWA = 10 \log \left[\frac{1}{480} \sum_{i=1}^{n} (2^{(L_{Ai}-85)/3} t_i) \right] + 85$$

Noise (continued):

- Frequency spectra of Aircraft (A/c):
- **Jet aircraft**: Noise Peak between 250 Hz to 2 kHz
- **Helicopters**: High at low rotation speed 12 – 20 Hz, Noise decrease linearly with frequency increase
- **Piston aircraft & turboprops**: Peak at about 60 Hz, decreases linearly with frequency

Noise (continues):

- Practical Counter-Measures to the Effects of Noise Exposure:
  - Use hearing protection
  - Ear plugs (30dB attenuation)
  - Communications headsets
  - Active noise reduction headsets

- **Noise (cont.):**
- Reduction of cabin noise:
  - Increasing canopy thickness
  - Damping cockpit walls
  - Smoothing aircraft surfaces
  - Redesigning air-condition systems
  - Helmets, headsets, earplugs (active & passive)
  - Active noise reduction (ANR) – destructive interference of the acoustic field
- Max noise level with zero risk: 75 dB

Noise (continues):

- Improving communication
  - Oxygen mask mounted microphones
  - Throat microphones
  - Noise canceling boom microphones
  - Helmets and headsets

Effects of Noise Exposure:

- Psychological
  - **Subjective Effects**
  - distraction, fatigue, irritability, startled responses,
  - poor sleep quality, loss of appetite,
  - headache, vertigo, nausea,
  - impaired concentration & memory.

Speech Interference:

- Noise can interfere with or mask normal speech, making it difficult to understand

Effects of Noise Exposure:

Psychological(cont):

- Loud noise higher than 100dB:
  - is a distraction & may lower performance
  - response time increases
  - can increase the number of errors in any given task
  - especially tasks that require vigilance, concentration,
  - calculations, and making judgments about time,.

Effects of Noise Exposure:

- Physiological
  - **Tinnitus**
  - **Ear discomfort** - up to 120 dB
  - **Ear pain** – at about 130 dB
  - **Eardrum rupture** may occur at 140 dB
  - **Temporary hearing impairment**
    - unprotected exposure to loud, steady noise
    - > 90 dB for a relative short time (several hours),
    - hearing returns to normal within several hours following cessation of the noise exposure

Noise (continues):

- Worst types of noise
  - Intermittent noise
  - Impulsive noise
  - High frequencies
- Compounding factors
  - Vibration,
  - heat,
  - hypoxia,
  - loss of sleep
  - Duration of exposure

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NOISE & VIBRATION(51)

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- Vision/eye problem?
- Noise over- load?
- Power- failure, or
- Airborne potty training?

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  - SAAsMA Members (for their contributions & slides)
    - Dr Chris Blunden (Previous SAAsMA President)
    - Dr Rob Bedford
  - SACAA
    - Dr Lesego (Head of Medical Section)
- References
  - Ernstein & King: “Aviation Medicine”
  - Kermode,A.C: “Mechanics of Flight”

Questions?