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Can we assess iMG signal quality on the field?

Dr Gregory Tierney

Ulster University

@GTBiomech

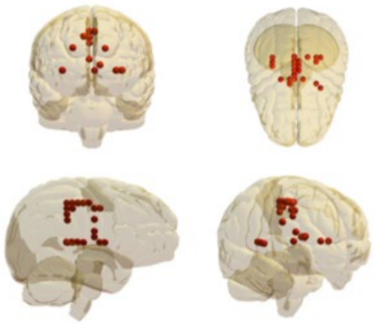
Conflicts of Interest

iMG Elite Arm Extension

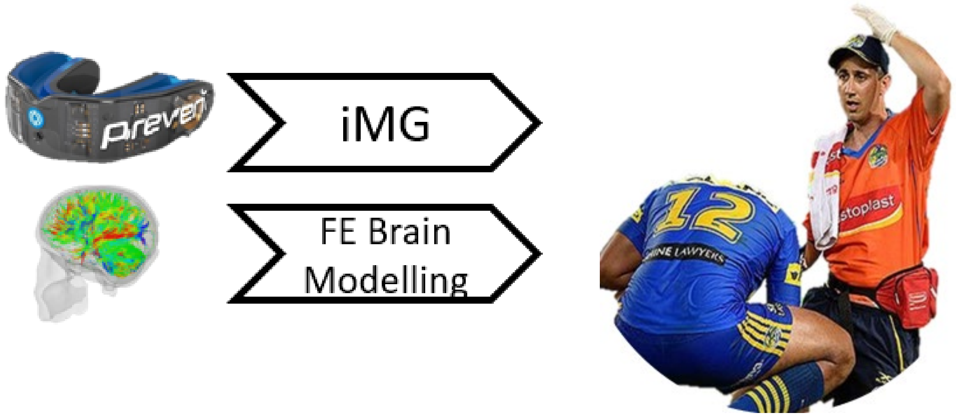
Player Head Acceleration Exposure Monitoring

Individual Player

Player Load



Biomechanical Mechanism of Head Accelerations and Concussion



iMG Validation

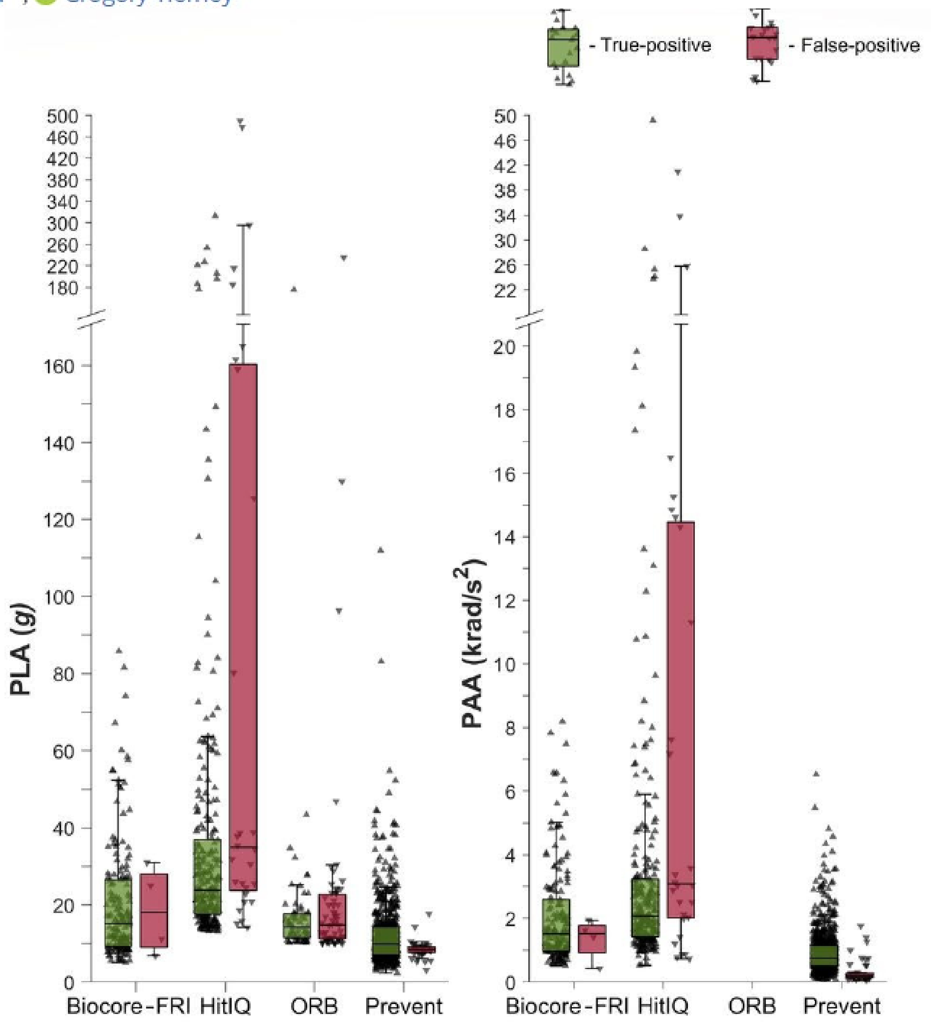
- Extreme differences in kinematics reported
- Restricts cross study comparison
- **Challenge**: What are realistic head kinematic signals

British Journal of
Sports Medicine

Original research

Ready for impact? A validity and feasibility study of instrumented mouthguards (iMGs) FREE

Ben Jones[1, 2, 3, 4, 5], James Tooby[1], Dan Weaving[1], Kevin Till[1, 3], Cameron Owen[1, 2], Mark Begonia[6], Keith A Stokes[7, 8], Steven Rowson[6], Gemma Phillips[1, 2, 9], Sharief Hendricks[1, 4], Éanna Cian Falvey[10, 11], Marwan Al-Dawoud[1], Gregory Tierney[12]



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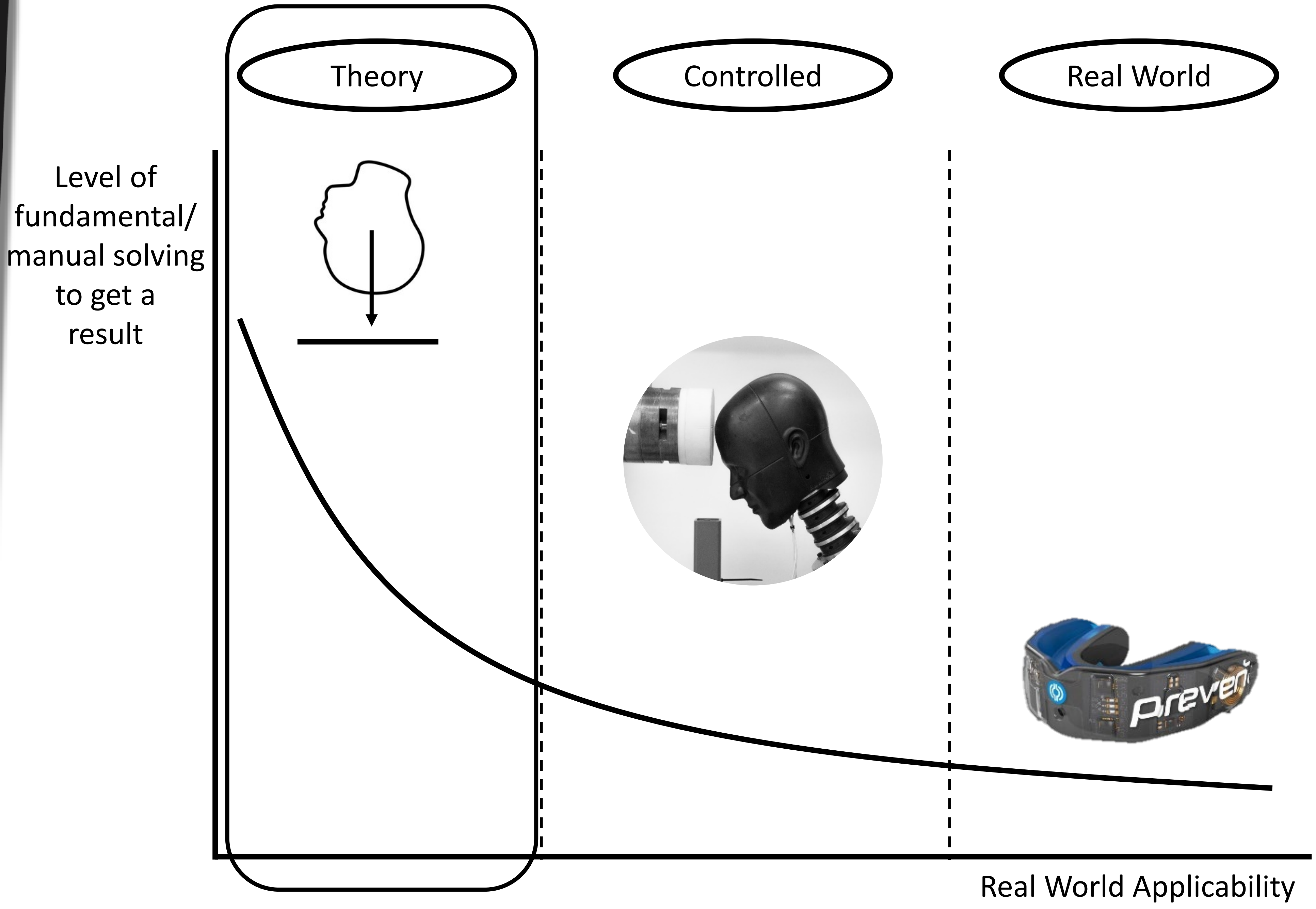
Biomechanical Approach



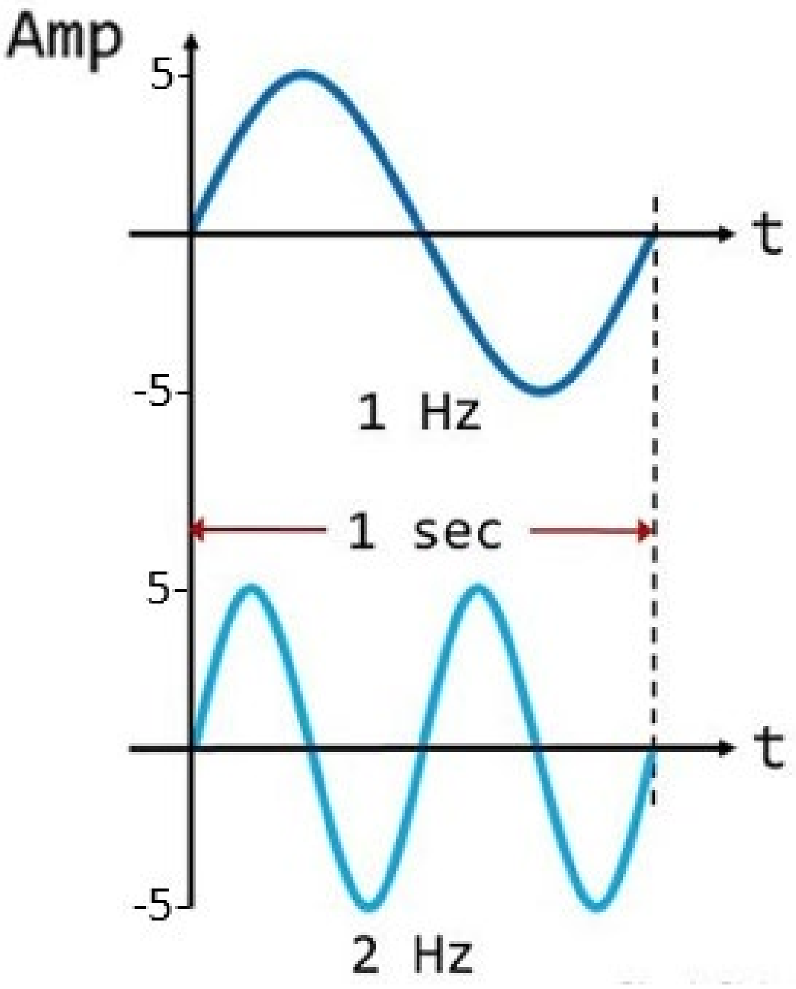
Basics of a Signal

Amplitude (A)
Maximum displacement from an equilibrium value.

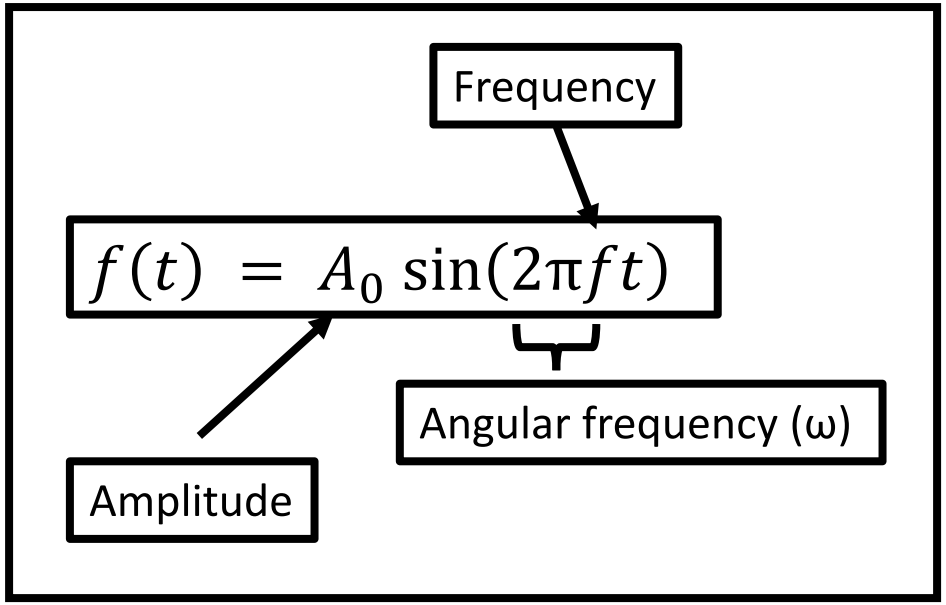
Frequency (f)
Number of cycles per second measured in Hertz (Hz)

Angular frequency (ω)
Measures angular displacement each second (rad/s)

Angular frequency = $\omega = 2\pi f$

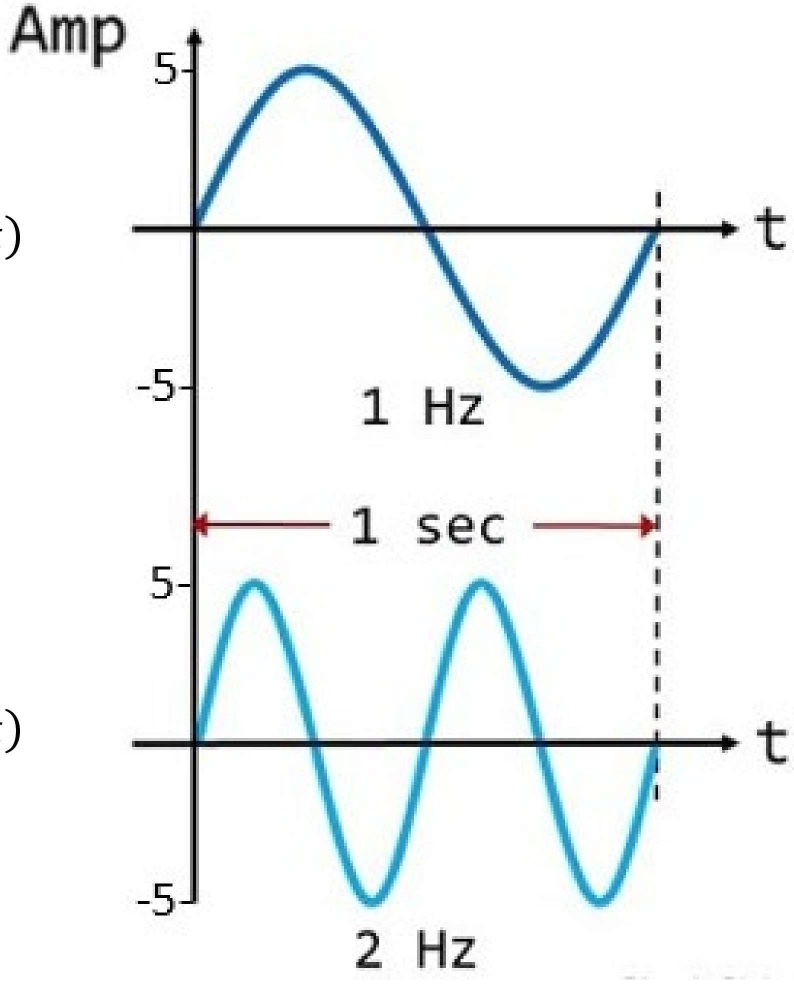


Basics of a Signal

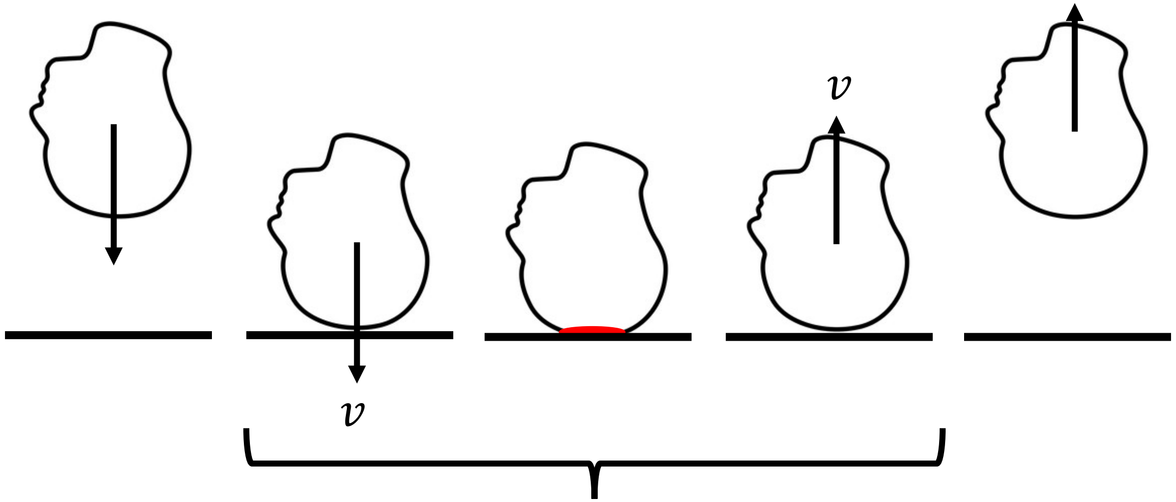


$A(t) = 5\sin(2\pi t)$

$A(t) = 5\sin(4\pi t)$

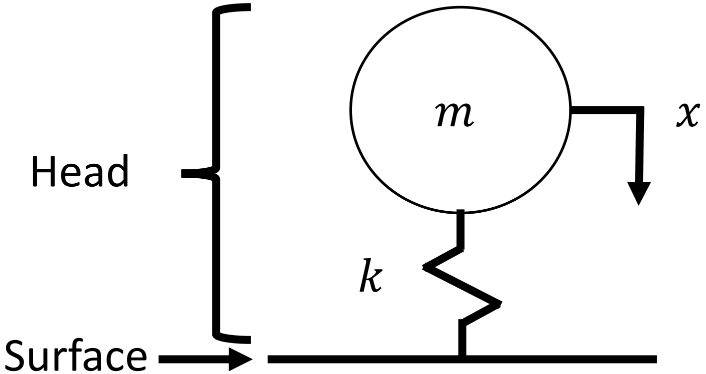


Rigid Body Mechanics – Elastic Head Impact



Spring mass system to represent head impact:

$$m\ddot{x}(t) + kx(t) = 0$$



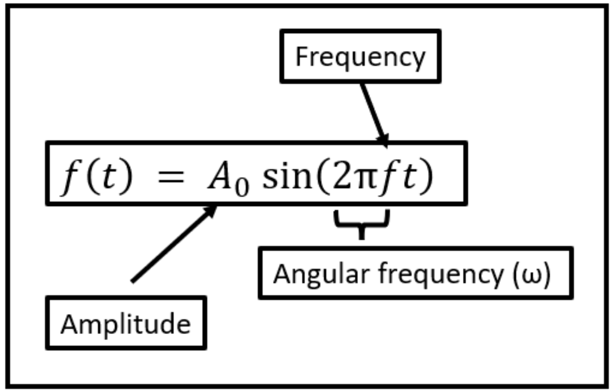
For known initial velocity

$$a(t) = -v\sqrt{\frac{k}{m}}\sin\left(\sqrt{\frac{k}{m}}t\right)$$

Amplitude (A_0)

Angular Frequency

Key:		
	m = Head Mass	v = Head Velocity
	k = Head Stiffness	a = Head Acceleration



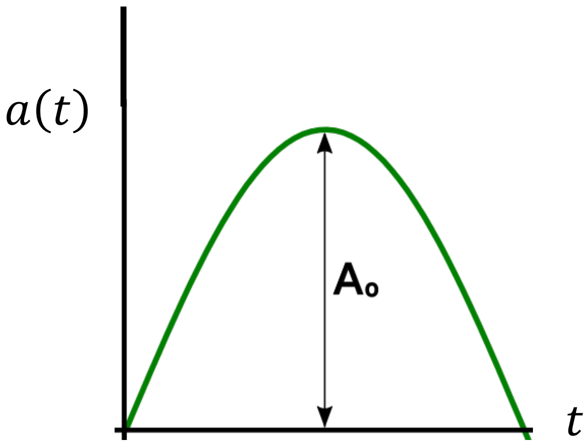
Rigid Body Mechanics – Elastic Head Impact

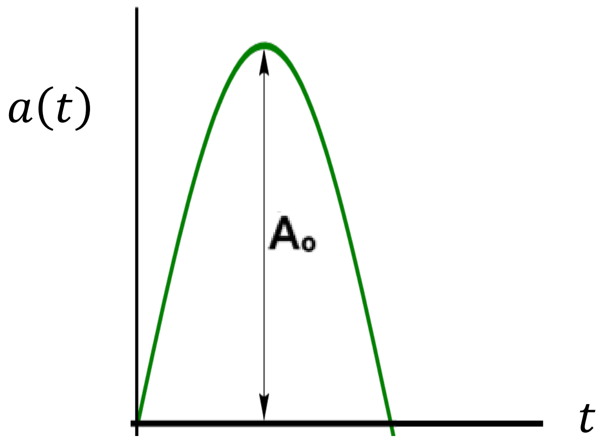
$$a(t) = \underbrace{-v\sqrt{\frac{k}{m}}}_{\text{Max Amplitude } (A_0)} \sin(\underbrace{\sqrt{\frac{k}{m}}}_{\text{Angular Frequency}}\, t)$$

Max Amplitude (A_0)

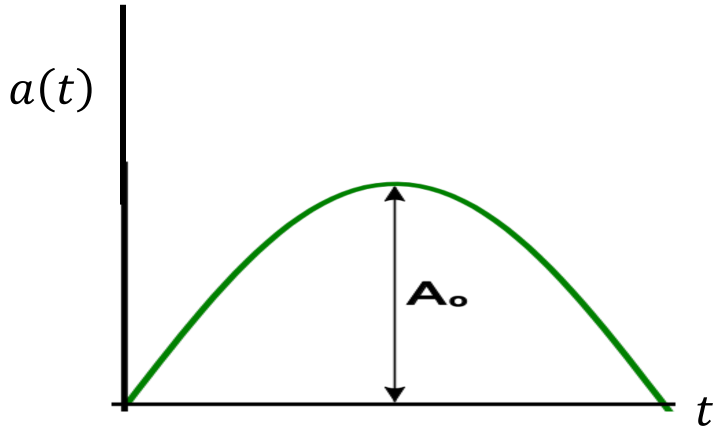
Angular Frequency

Key: m = Head Mass
k = Head Stiffness
v = Head Velocity
a = Head Acceleration



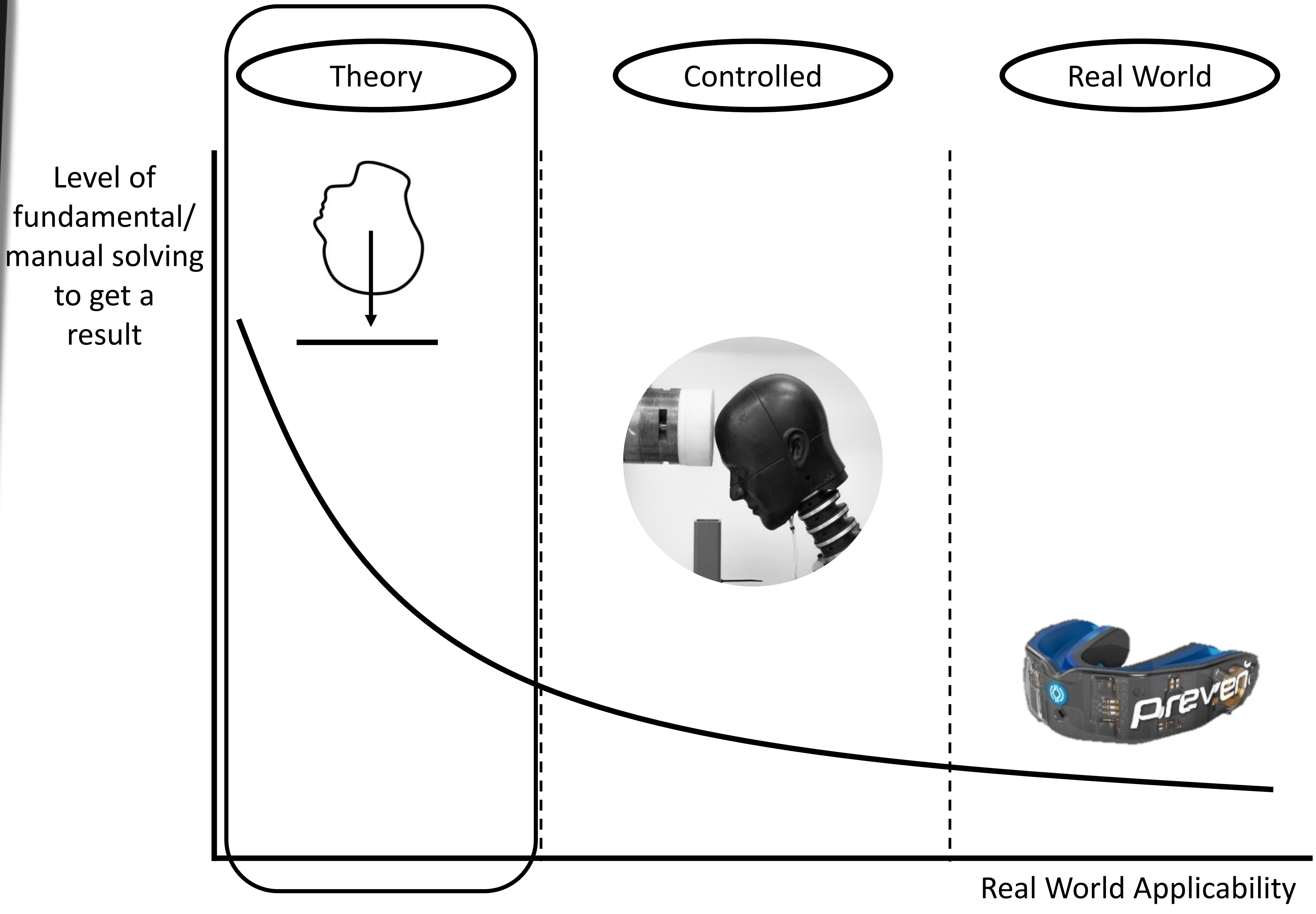


Stiffer impact



Softer impact

Biomechanical Approach



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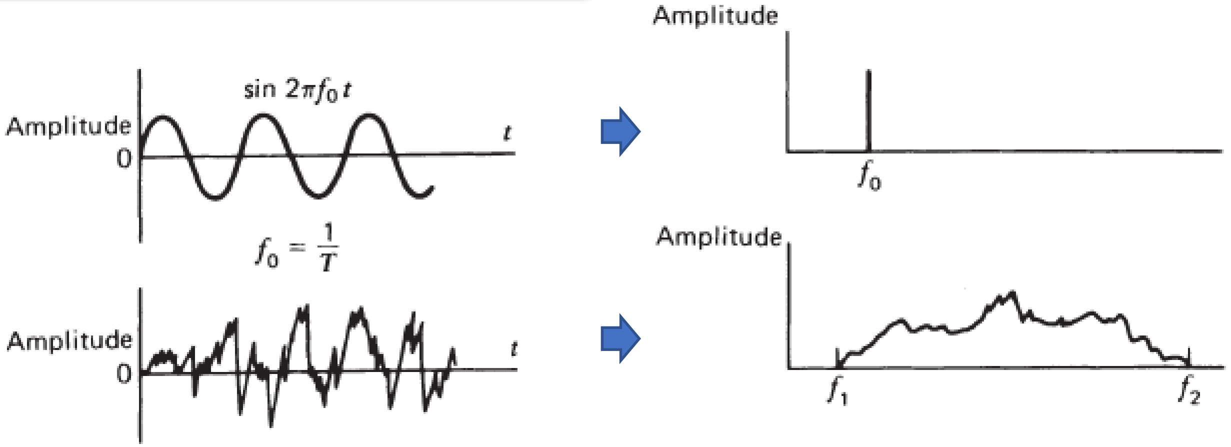
Basics of a Signal

Theoretical Example

Real World



Causes of Frequency Spectrum during head impacts

True Signal

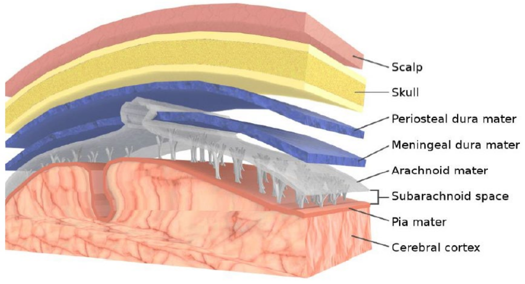
- Complex contact characteristics and dynamics

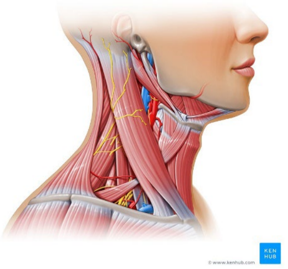
Noise

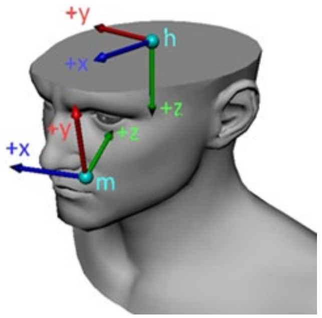
- Caused by errors in measurement system and mathematical calculations

Artefacts

- To be discussed





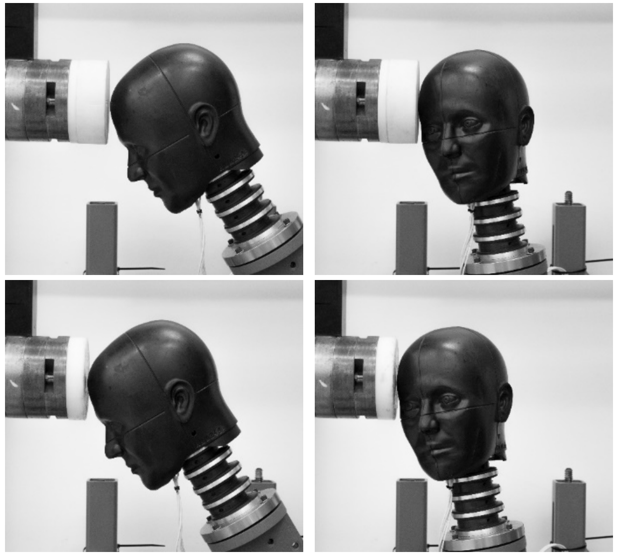


Head Impact Testing Lab

Front | Front Boss

Padded Impactor (VN foam)

Rigid Impactor (Nylon)



Headform

- 3 accelerometers
- Tri-axial angular rate sensor

- 20 kHz (No Filter)

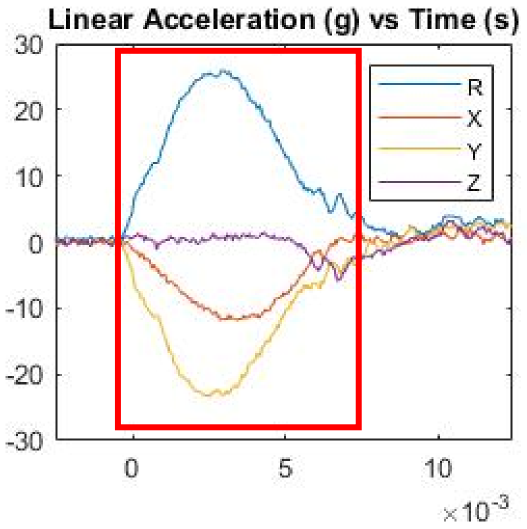
Testing Protocol

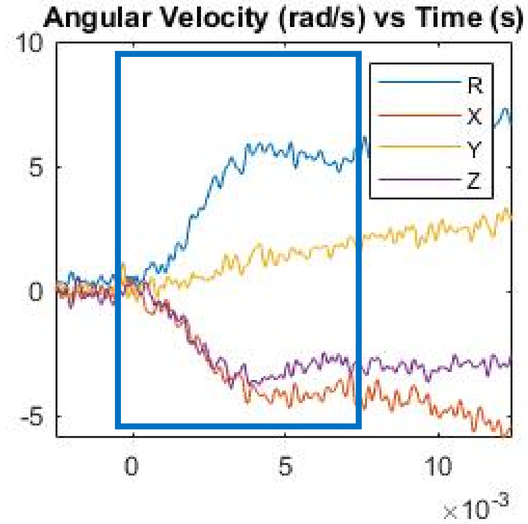
- 2 impact Locations
- 6 impact magnitudes (25-150 *g*)
- 2 impact contact conditions (padded and rigid)
- 3 impacts per condition

- 72 impacts total

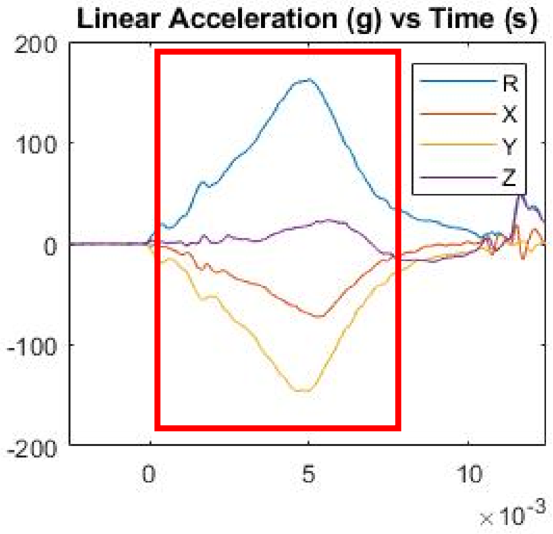
Head Impact Testing Lab

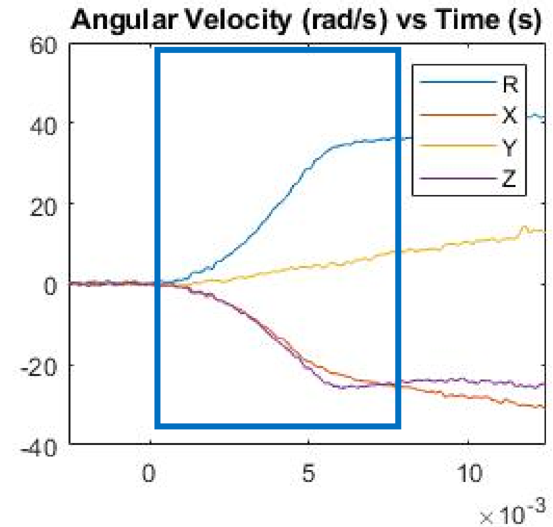
25 *g* Impact



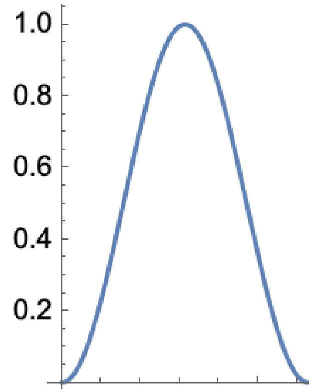


150 *g* Impact

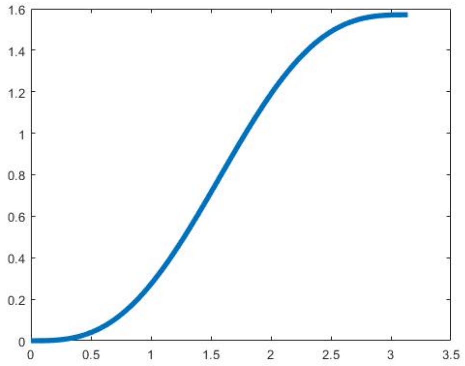




Acceleration Pulse Shape

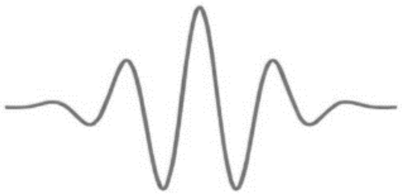


Velocity Pulse Shape

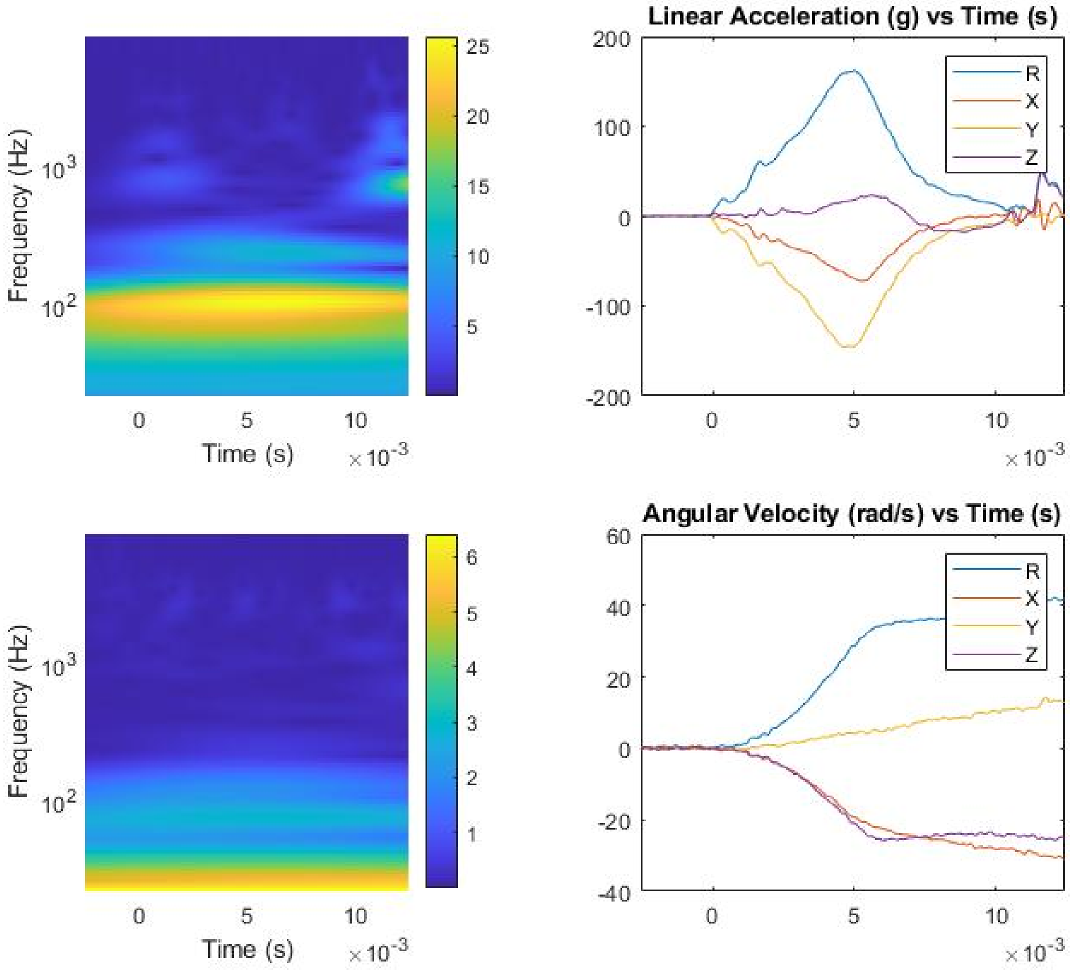


Head Impact Testing Lab

Wavelet Transformations

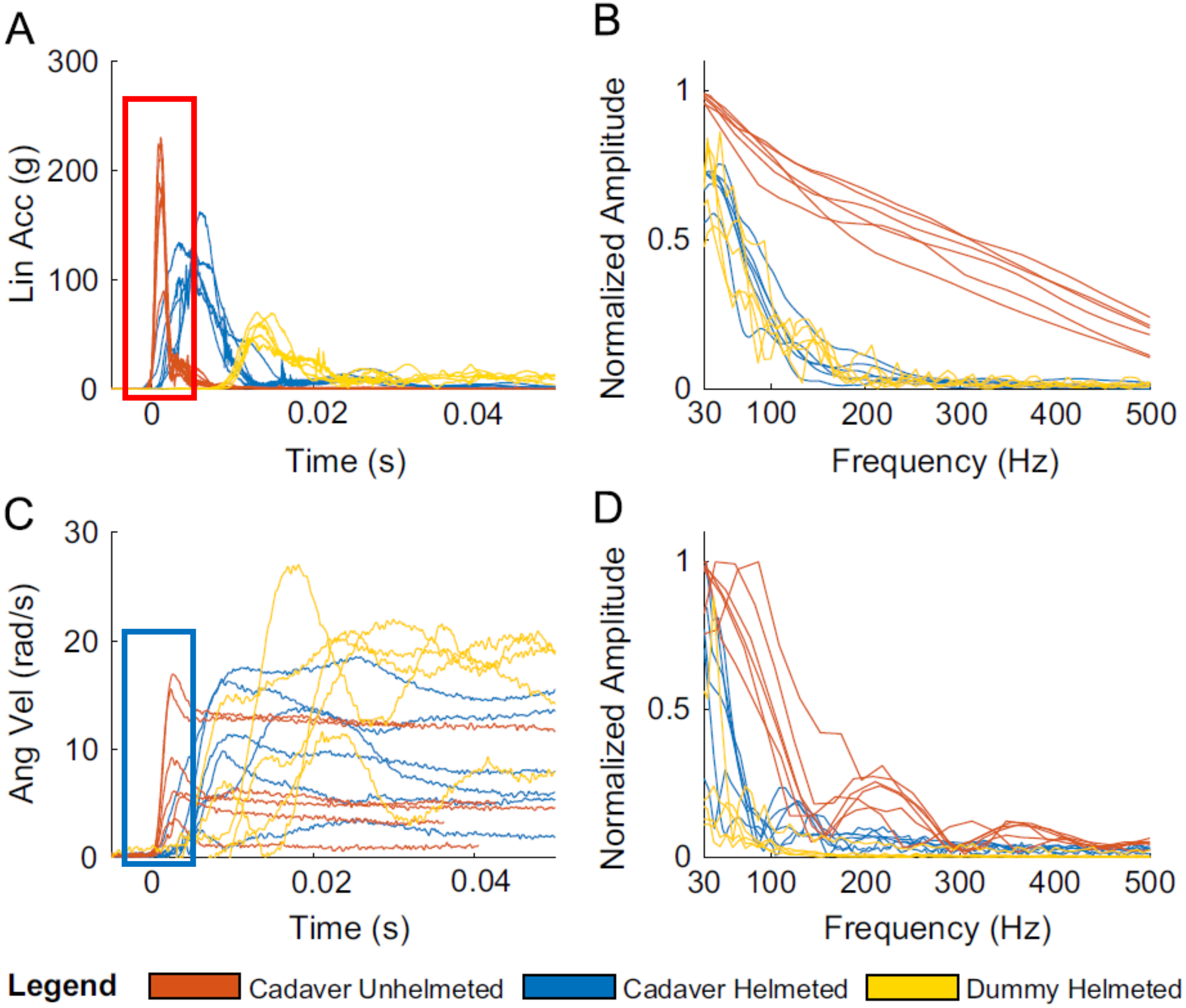


	Linear Acceleration (Hz)	Angular Velocity (Hz)
Median	106	24
Max Value	311	78

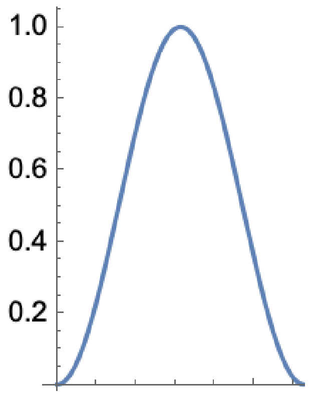


Comparison to Cadaver Tests

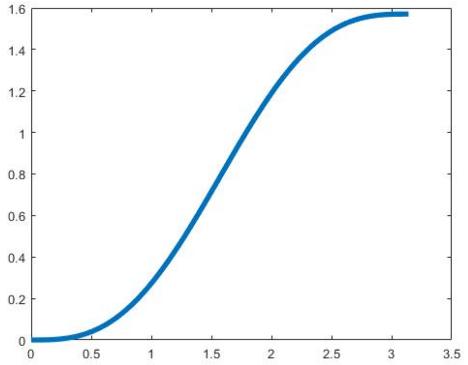
Wu et al. 2016. J Biomech



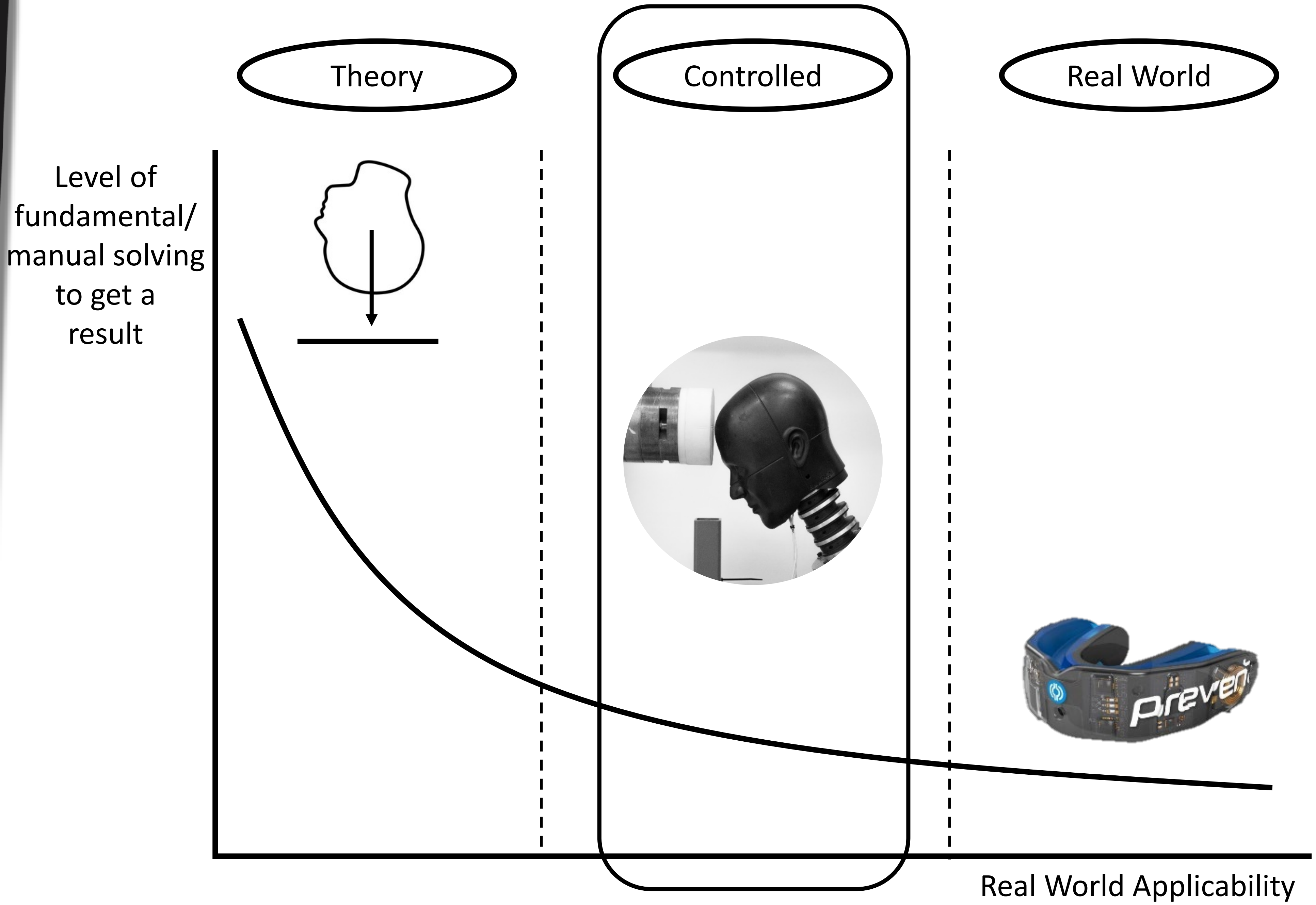
Acceleration Pulse Shape



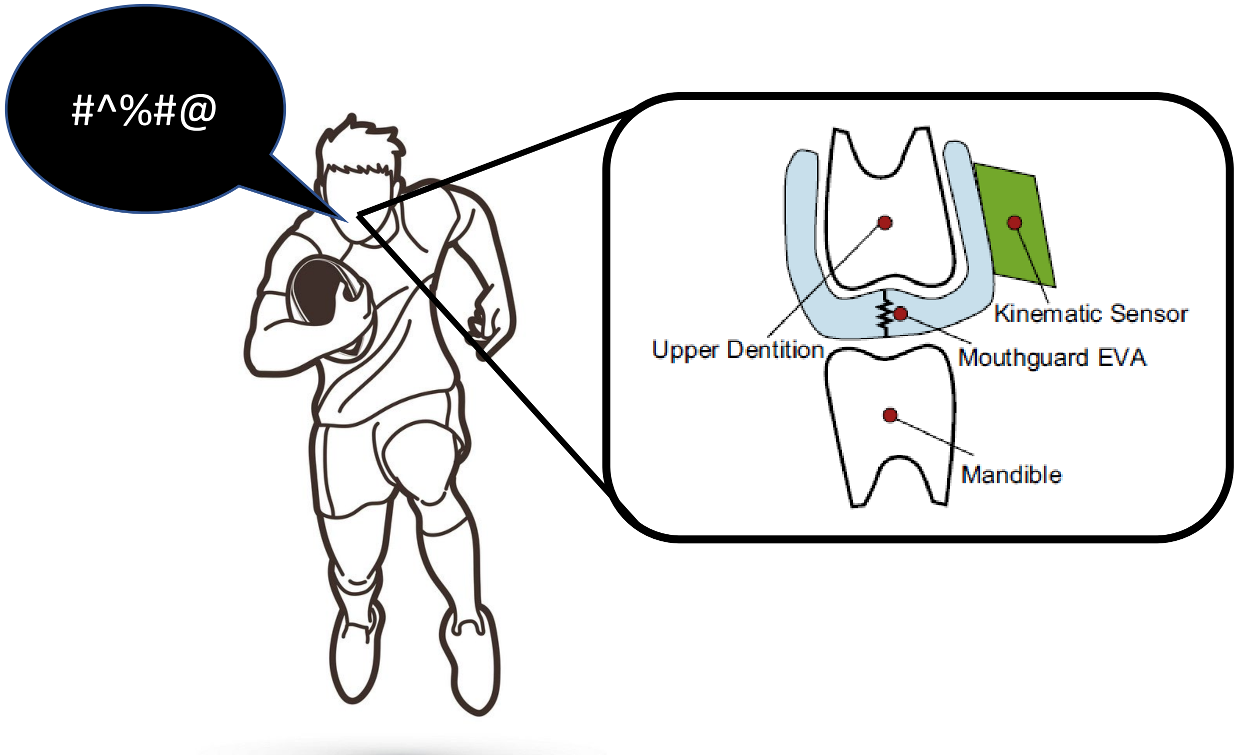
Velocity Pulse Shape



Biomechanical Approach



Artefacts



Sources of Artefacts

- Shouting
- Poor fit
- Biting
- Mandible interference
- Direct impact to iMG
- Sensor vibration

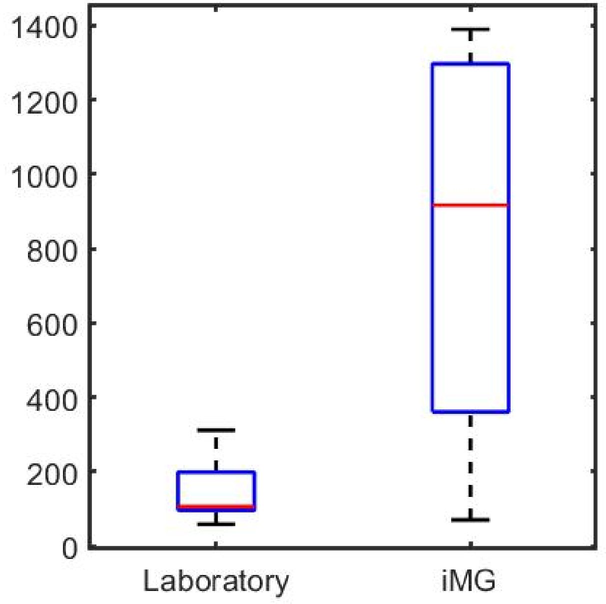
Methods

- Participants (Northern Hem)
  - 4 male and 3 female elite teams
- Prevent Biometrics custom fit iMGs
- Accelerometer and gyroscope sampling at 3200 Hz
- 5695 head acceleration events
- Raw data showed **<u>71</u>** impacts greater than 150 g (resultant) at head Centre of Gravity (CG)

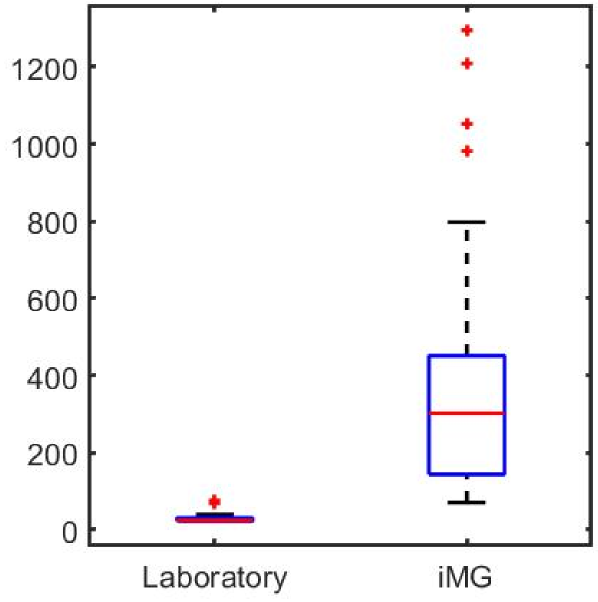
>150 *g* events – Wavelet Transformations

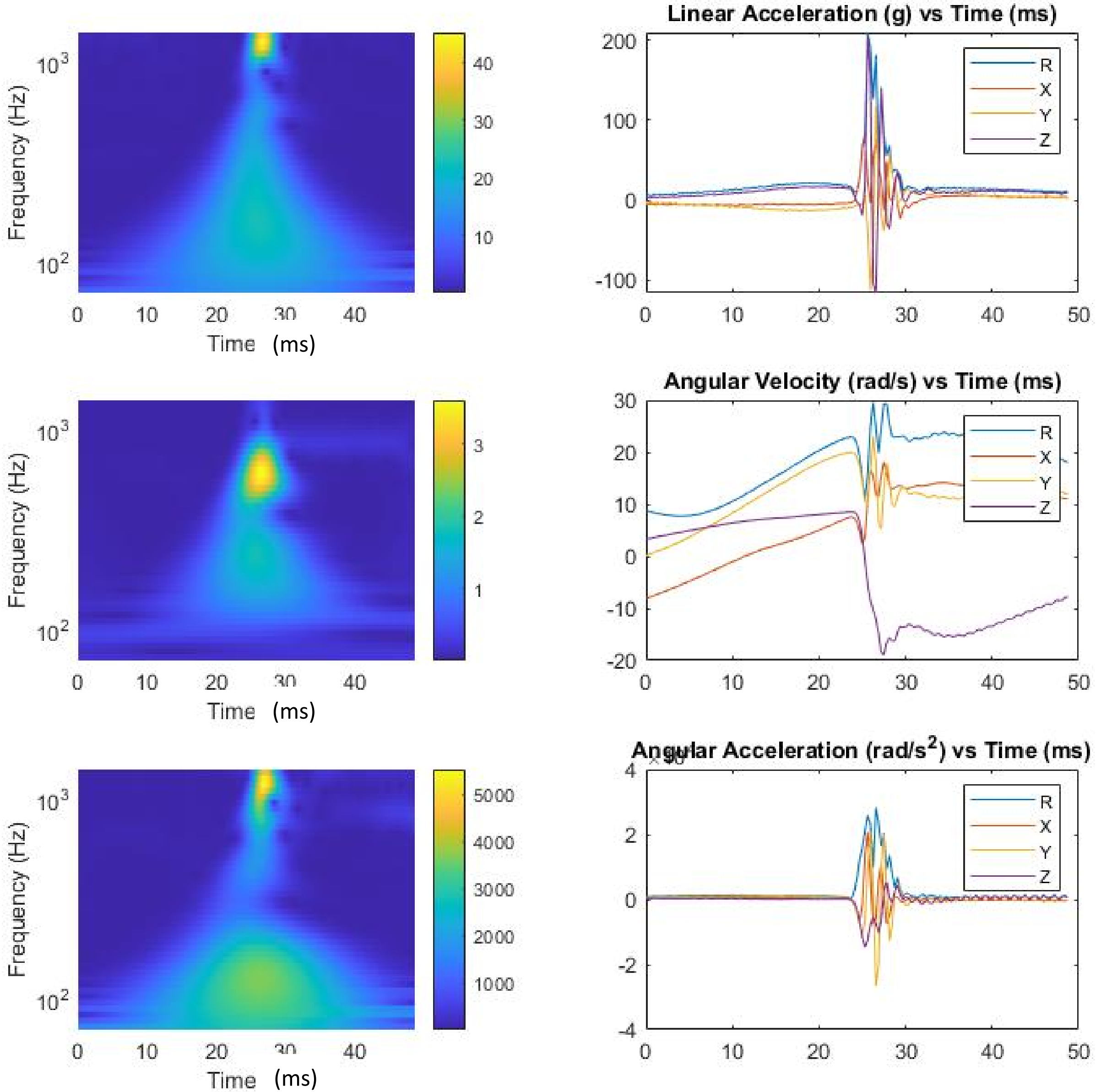
Primary Frequency at Impact Pulse

Linear Acceleration



Angular Velocity

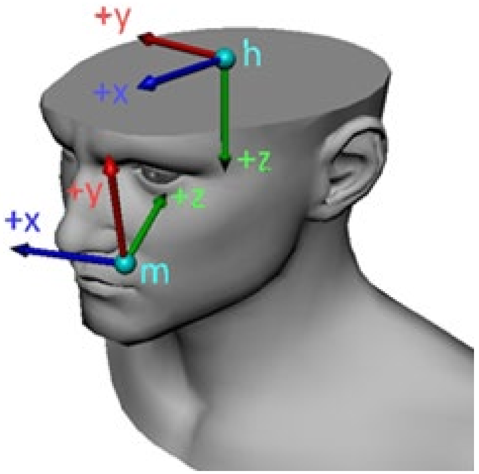


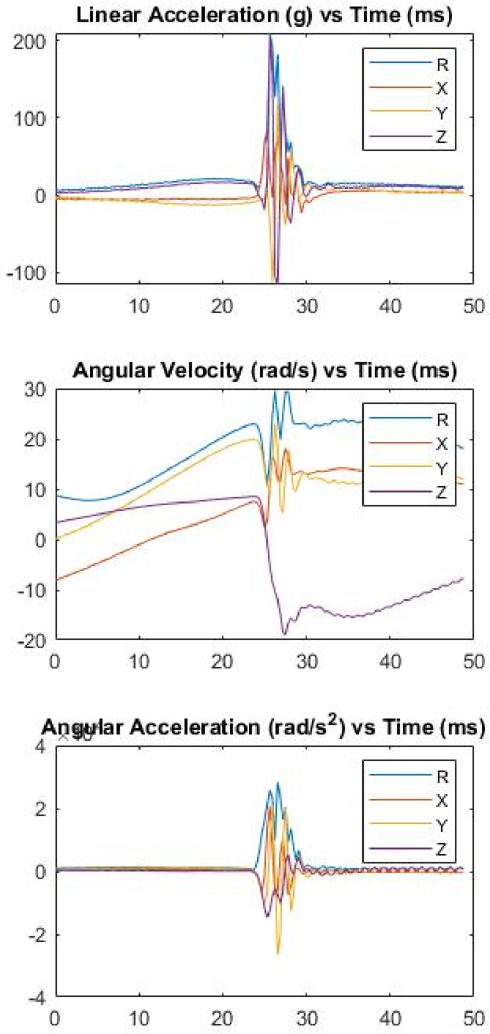


>150 *g* events - Artefact

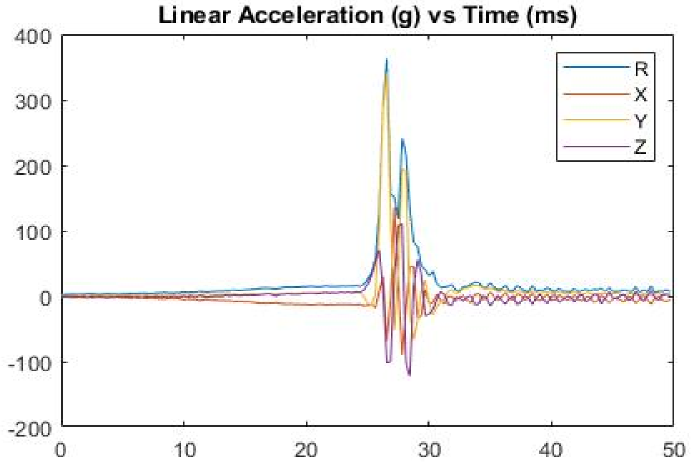
Artefact Example

- Transform from iMG to Head CG **without** filtering



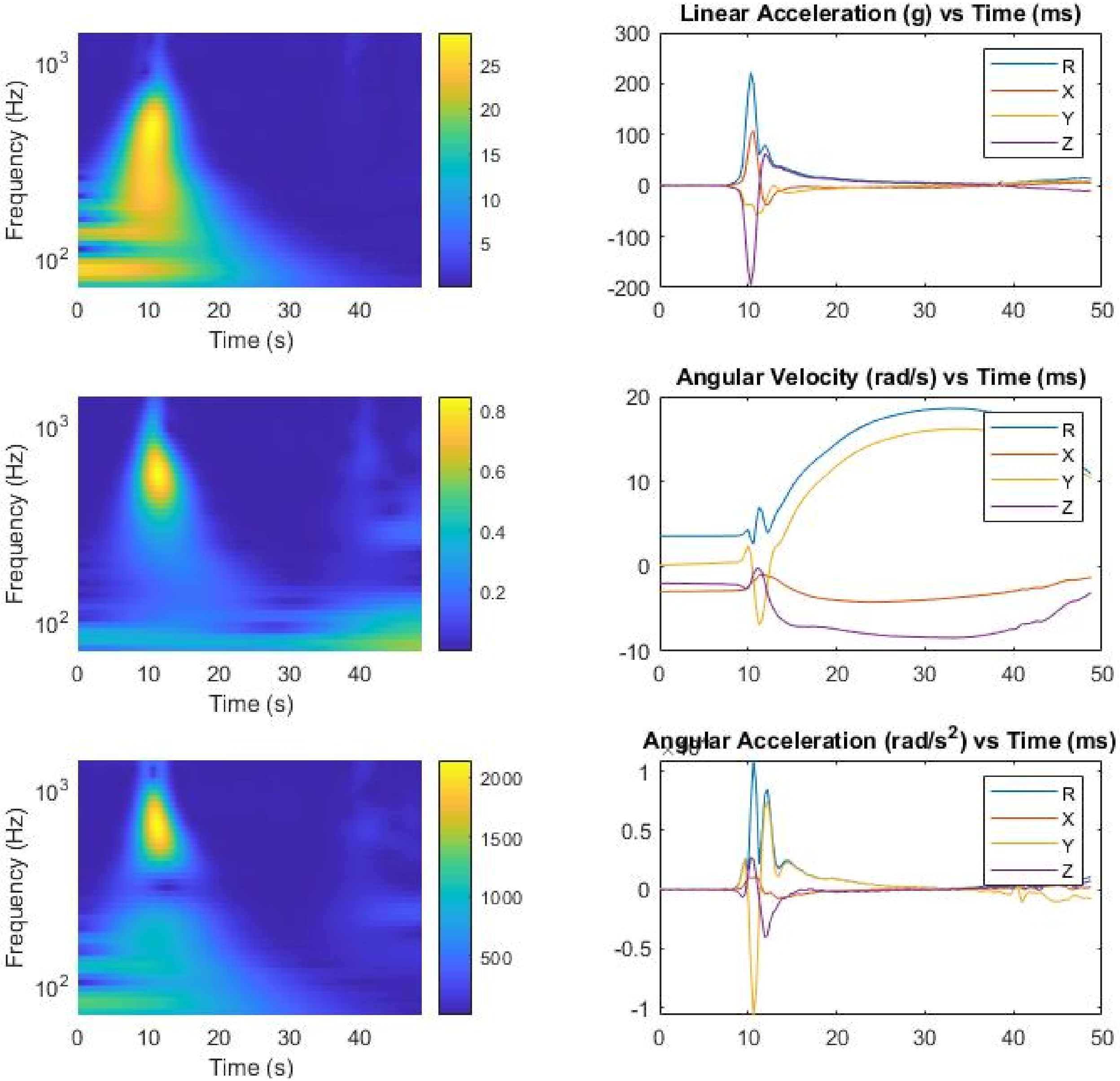


iMG = 210 *g*



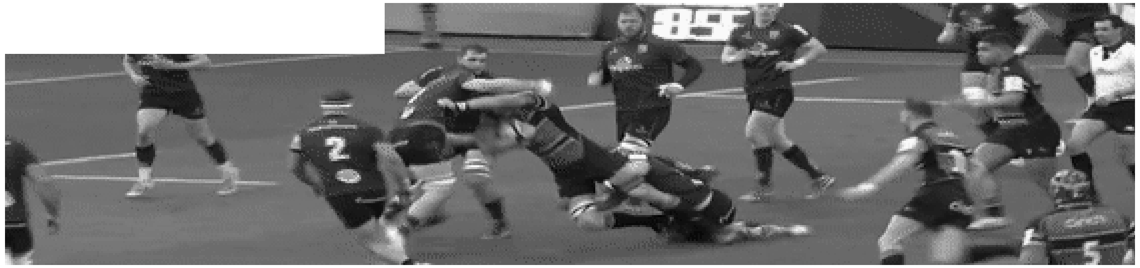
Head CG (no filter) = 362 *g*

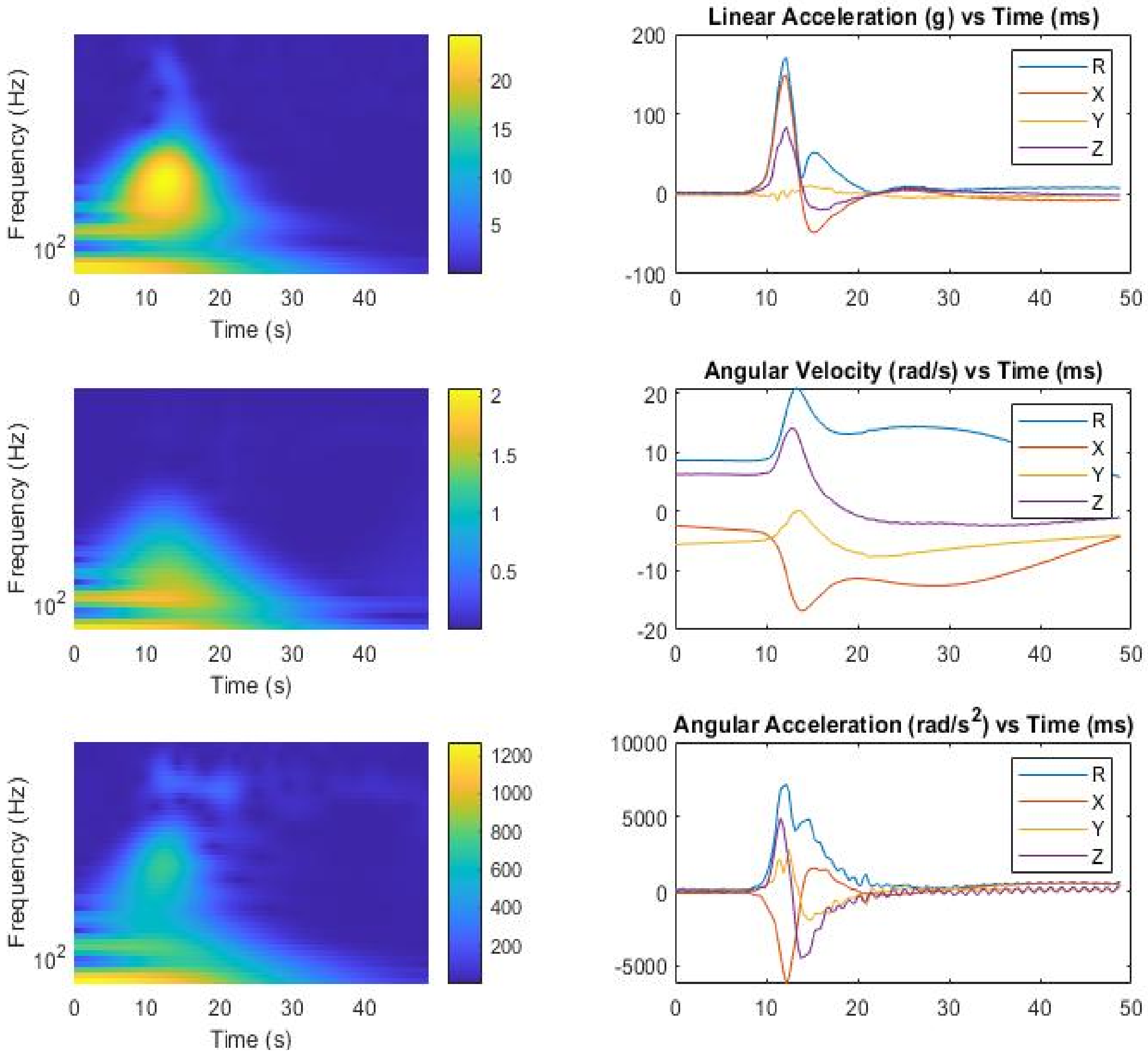
>150 *g* events - Artefact



>150 *g* events - Cleaner

Cleaner Example

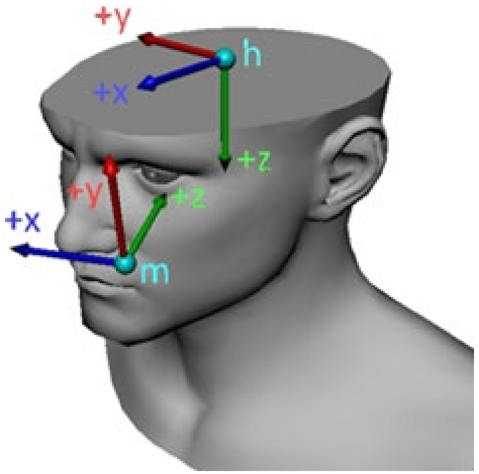


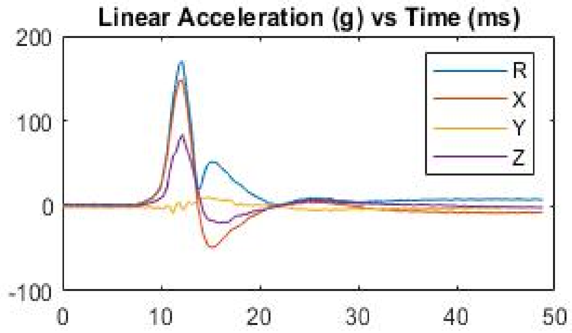


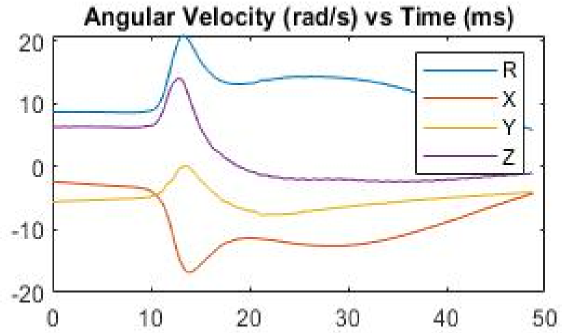
>150 *g* events - Cleaner

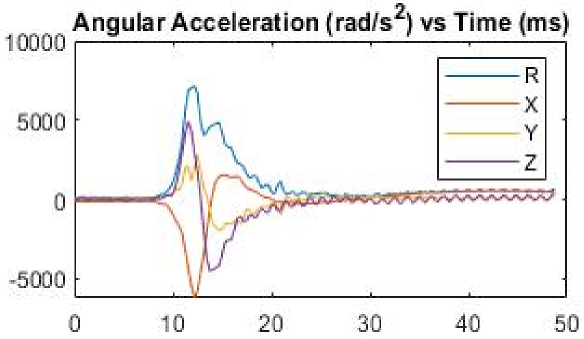
Artefact Example

- Transform from iMG to Head CG **without** filtering

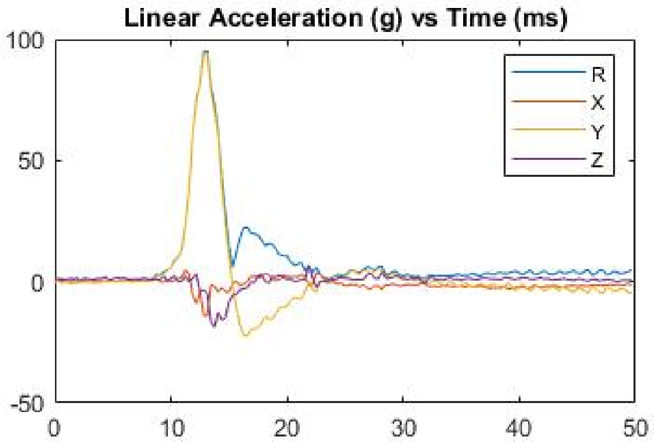








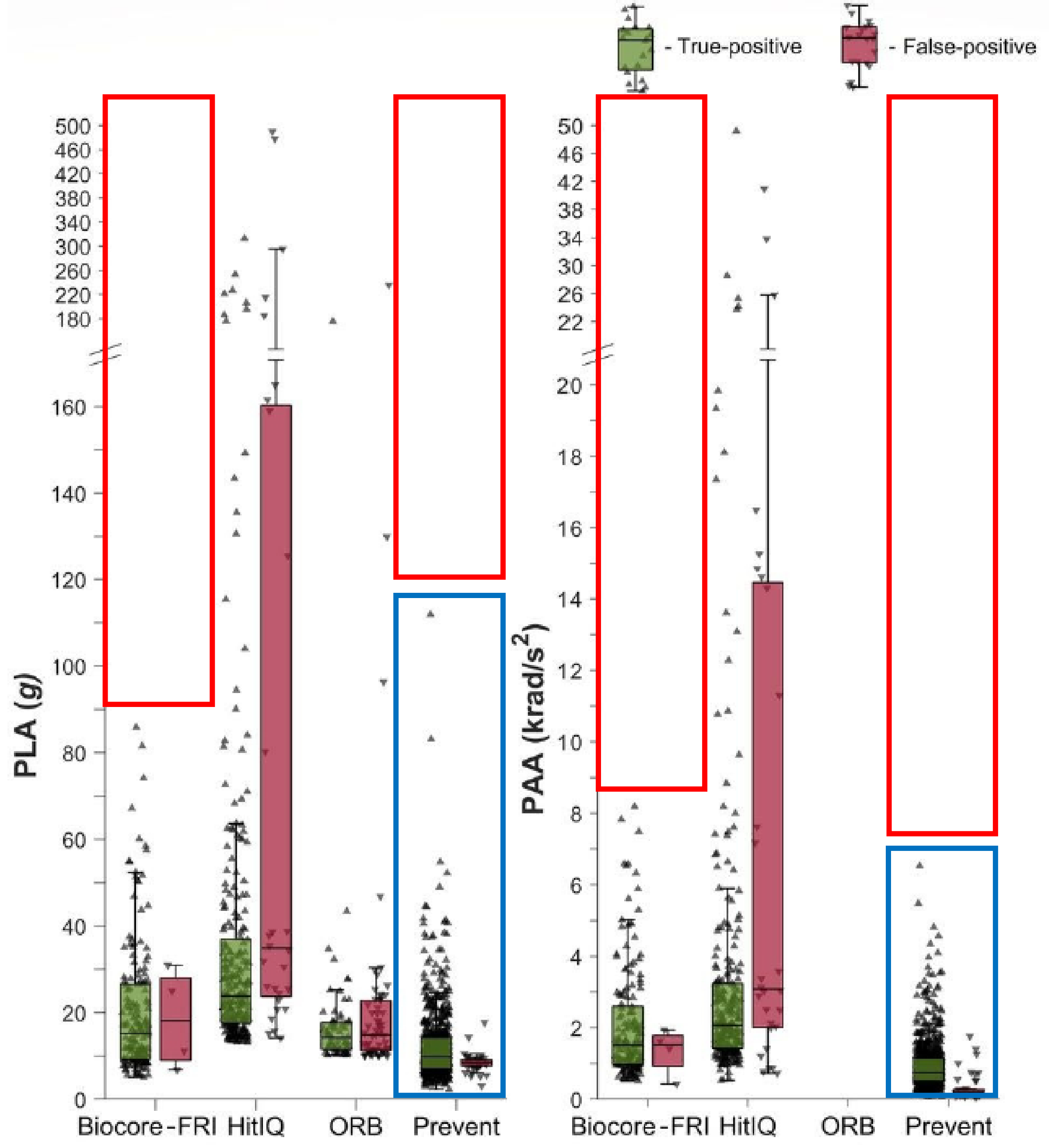
iMG = 171 g



Head CG (no filter) = 95 *g*

iMG Validation

- Extreme differences in kinematics reported
- Restricts cross study comparison
- **<u>Challenge</u>**: What are realistic head kinematic signals



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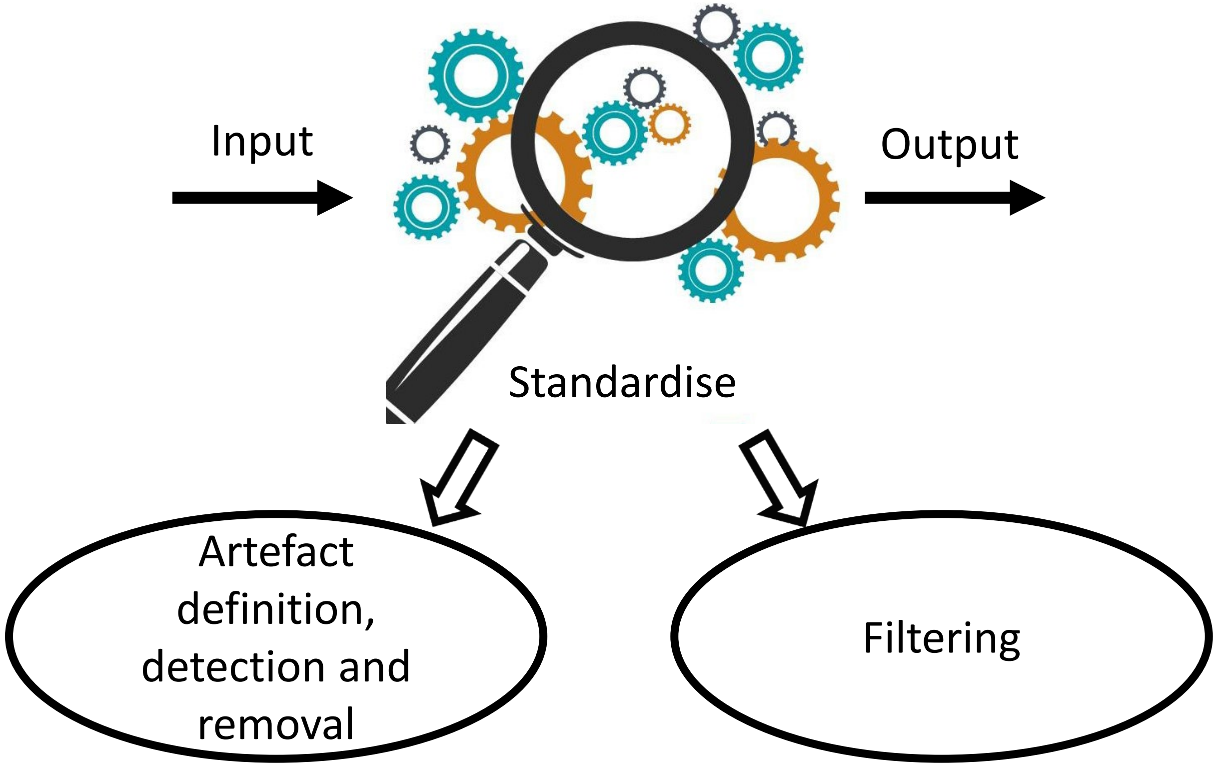
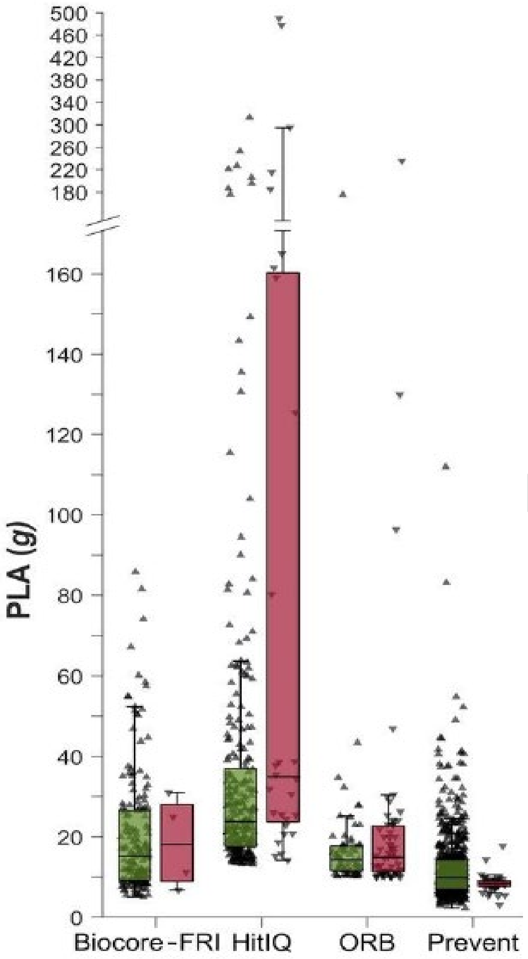
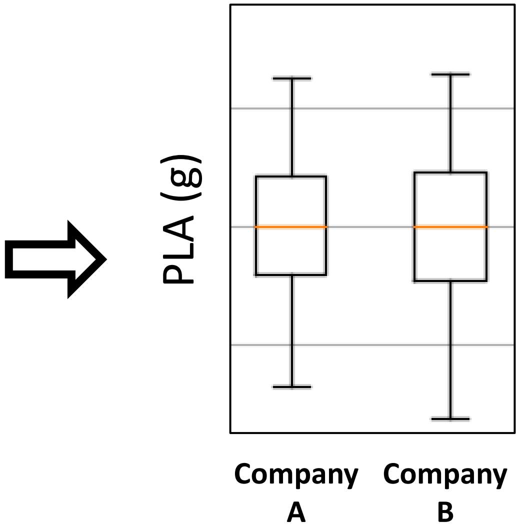
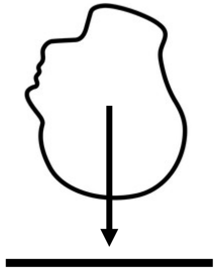
Post-processing of iMG signals







Conclusion



Theory

- Impact pulse/frequency influenced by impact conditions (e.g., mass and stiffness)

Laboratory

- Acceleration -> Haversine pulse; Velocity -> S-shaped pulse
- Frequency during impact pulse relatively low

On-field

- Artefacts characterised by high-frequency, relatively high amplitude components in signal
- Artefacts produce erroneous and high peak kinematics at Head CG

Acknowledgments

James Tooby

James Woodward

iMG Elite Arm Project

Project team:
Dr Éanna Falvey
Prof Ross Tucker
Dr Danielle Salmon & team
Dr Melanie Bussey & team
Ben Hester & team
James Tooby
James Woodward
Lindsay Starling

All Participating clubs

Thank you for listening!

Can we assess iMG signal quality on the field?

Dr Gregory Tierney

Ulster University

@GTBiomech