Wearable monitoring of cardiovascular changes during two months of head-down bed rest

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Overview

1 Introduction

2 Methods

3 Results

4 Discussion & Conclusion

Objective: Show that you can do physiology, even when you are an aerospace engineer / astrophysicist, and that there can be applications on Earth!

1

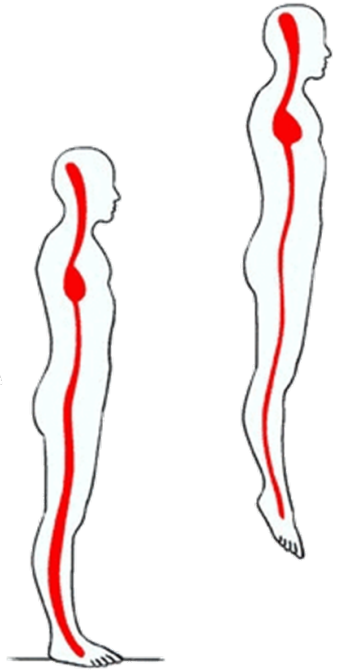
Introduction

Context
Ballisto- & Seismocardiography?
Objectives & Hypotheses

Hydrostatics

On arrival in weightlessness

Normal terrestrial conditions



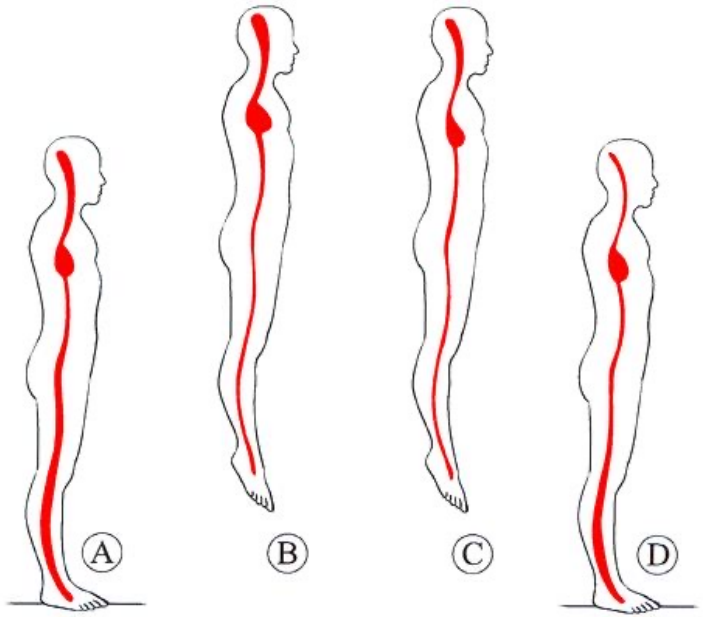
Hydrostatics

Ground

Space

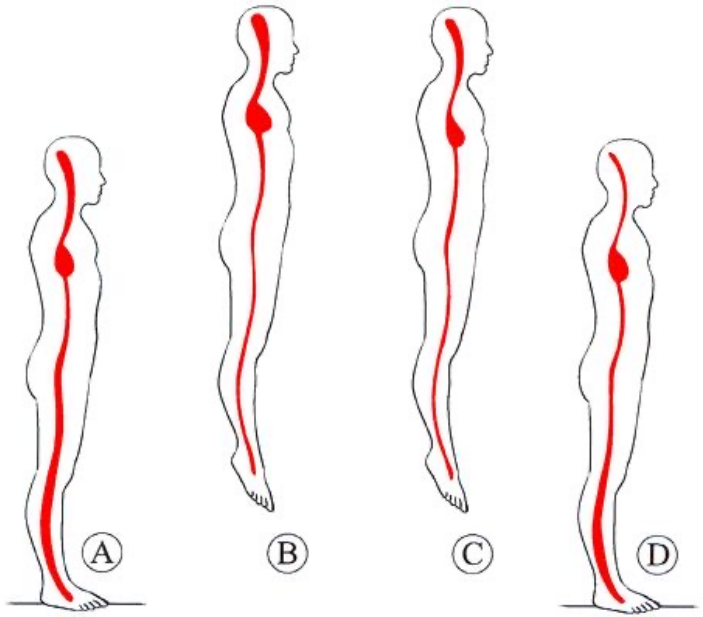
Adaptation

- Decrease of blood volume
  - Through sweat and urine
  - -10% in 10 days
- Decrease of cardiovascular reactivity
  - Baroreceptors less stimulated
- Deconditoning of cardiac muscle
  - Hypokinesia



Consequences

- On return to the Earth
  - Orthostatic hypotension
  - Fainting



Microgravity:
a hostile environment for the cardiovascular system

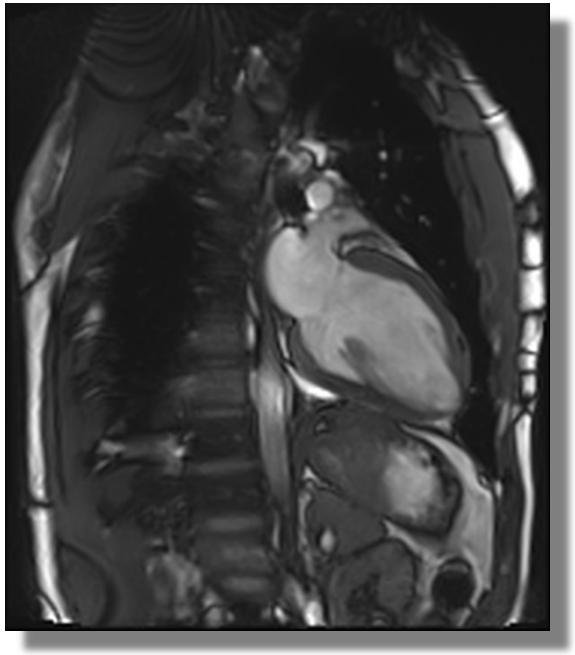
Credits: NASA, Roscosmos

Objectives

- Evaluate the impact of long-term exposure to (simulated) microgravity on BCG & SCG
- Compare metrics recorded using portable cardiac monitoring to those acquired by MRI

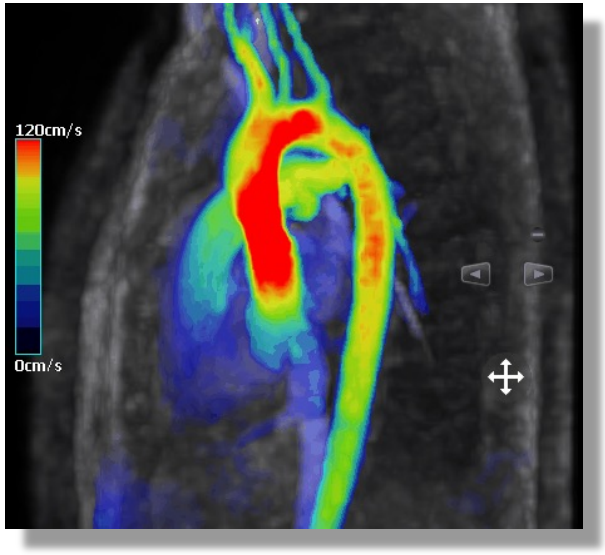
Seismocardiography (SCG)

- The heart is moving
- Blood is going from one chamber to another and then in the arteries
- ➢ Record vibrations on the surface of the chest

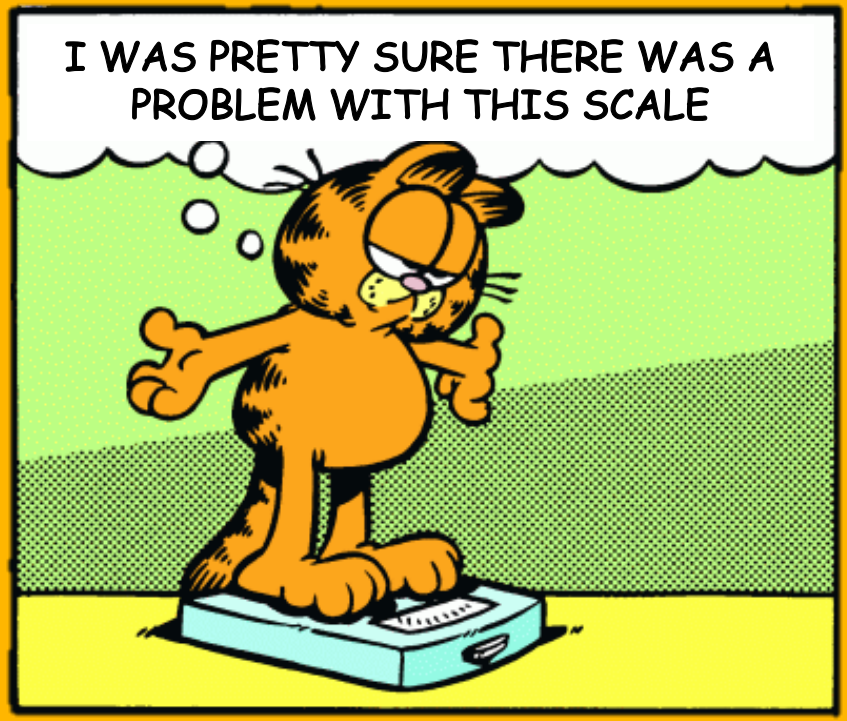


Ballistocardiography (BCG)

- Anisotropy of the arterial tree
- As blood is flowing, the center of mass is slightly moving
  - ➢ Record vibrations at the center of mass



If your weighing scale is accurate enough, the needle indicating your weight should move as your heart beats

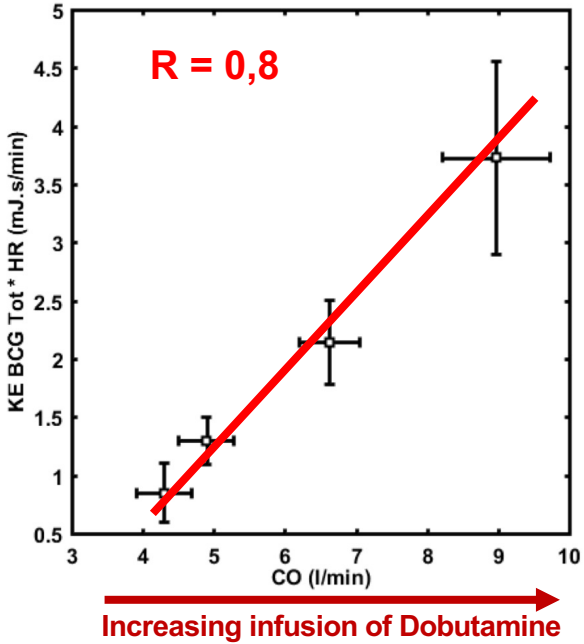


Adapted from PAWS, INC

Recent findings

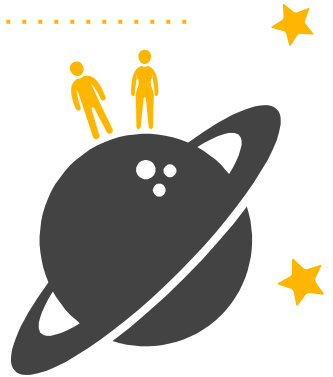
- **Recent clinical study:**
  Evaluation of the effect of increasing heart contractility on the BCG metrics

- Double blind crossover:
  Placebo vs. Dobutamine (34 healthy subjects)



Hossein et al. (2019)

Hypotheses



- After exposure to (simulated) microgravity, integral of kinetic energy recorded by SCG & BCG is lower than at baseline
- This decrease is less pronounced in a countermeasure group than in a control group
- SCG & BCG metrics correlate to MRI stroke volume and peak ejection velocity

2

Methods

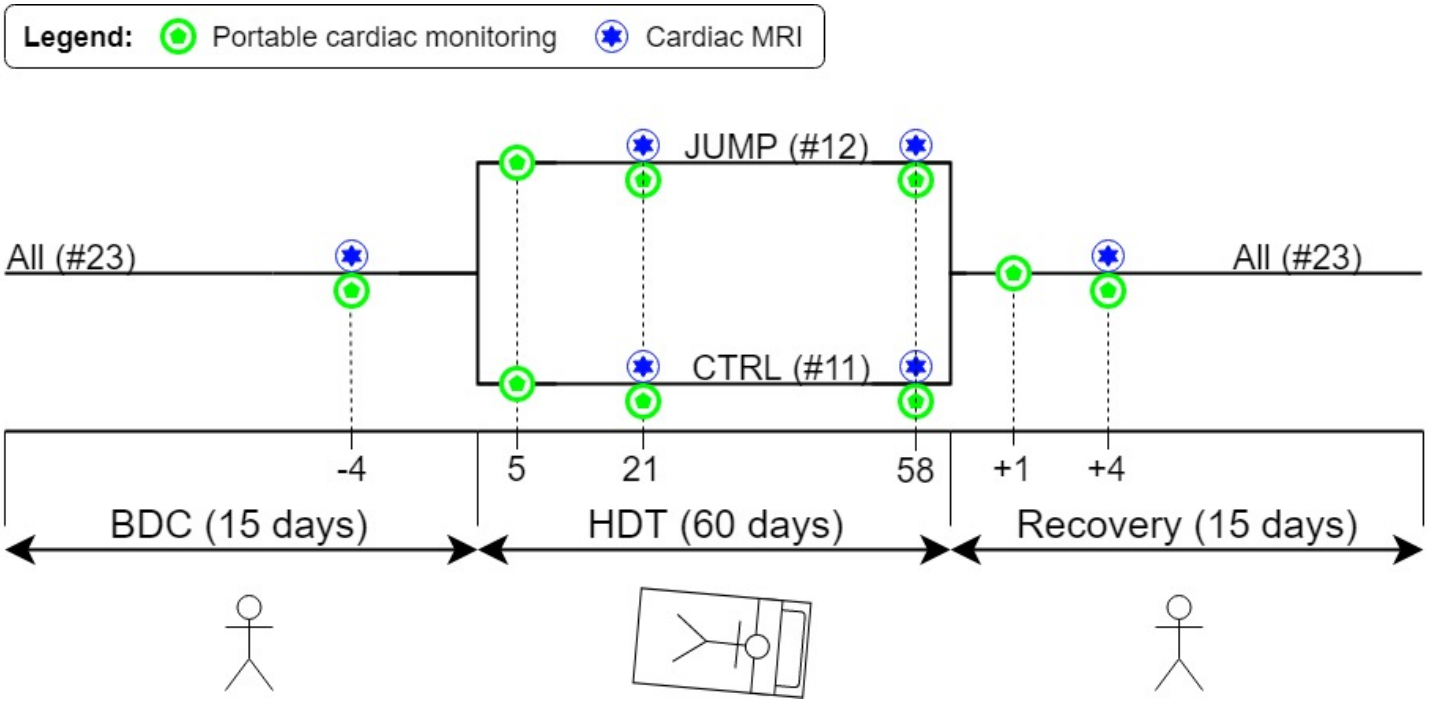
Head-Down Tilt Bed Rest
SCG & BCG protocols
MRI protocols

Bedrest & Countermeasure

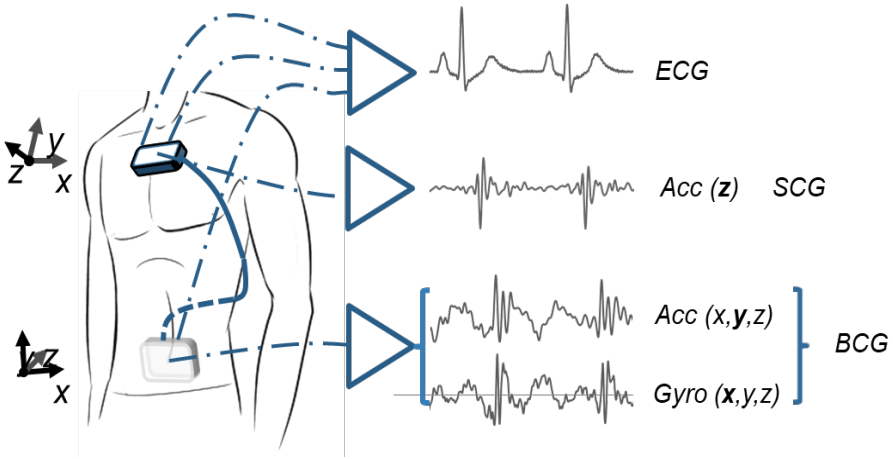
- ESA-RSL head-down tilt (-6°) bed rest study
- 23 healthy male subjects
- **Countermeasure:**
  Physical training procedure based on jumps in horizontal position (6 times per week)

Credits: DLR

Time Points


Legend:
Portable cardiac monitoring
Cardiac MRI
JUMP (#12)
All (#23)
All (#23)
CTRL (#11)
-4
5
21
58
+1
+4
BDC (15 days)
HDT (60 days)
Recovery (15 days)

Portable cardiac monitoring

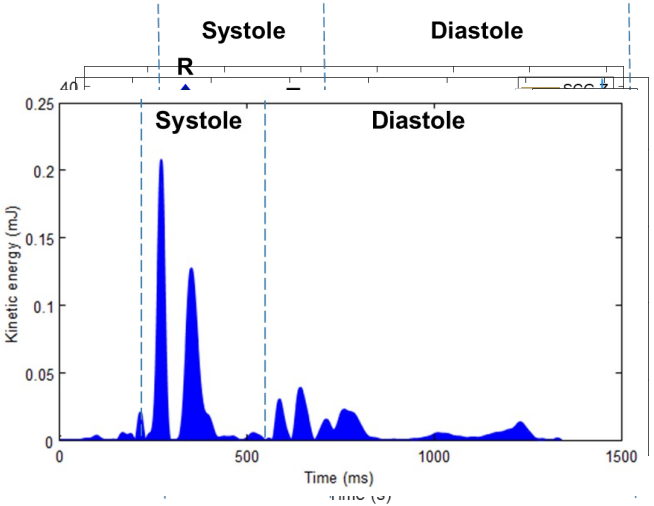


- Motionless in supine position or HDT
- Imposed controlled breathing (8-s breathing cycles)

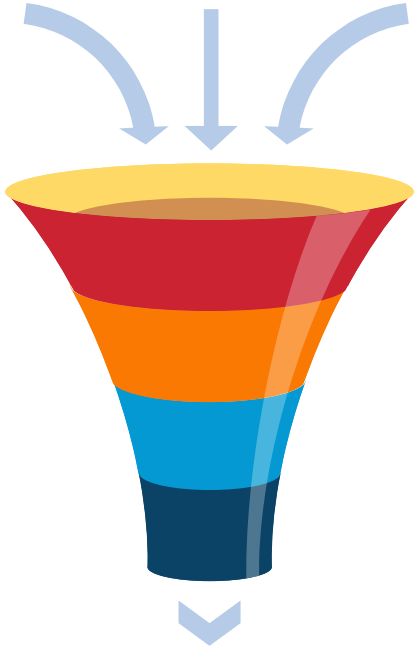
Height & Weight

ECG Signal

SCG & BCG Signals



iK SCG (J.s)



Metrics of interest

1. Acquire accelerometric signal
2. Compute kinetic energy
3. Detect heartbeats and cardiac phases
4. Compute ensemble average

MRI Protocols

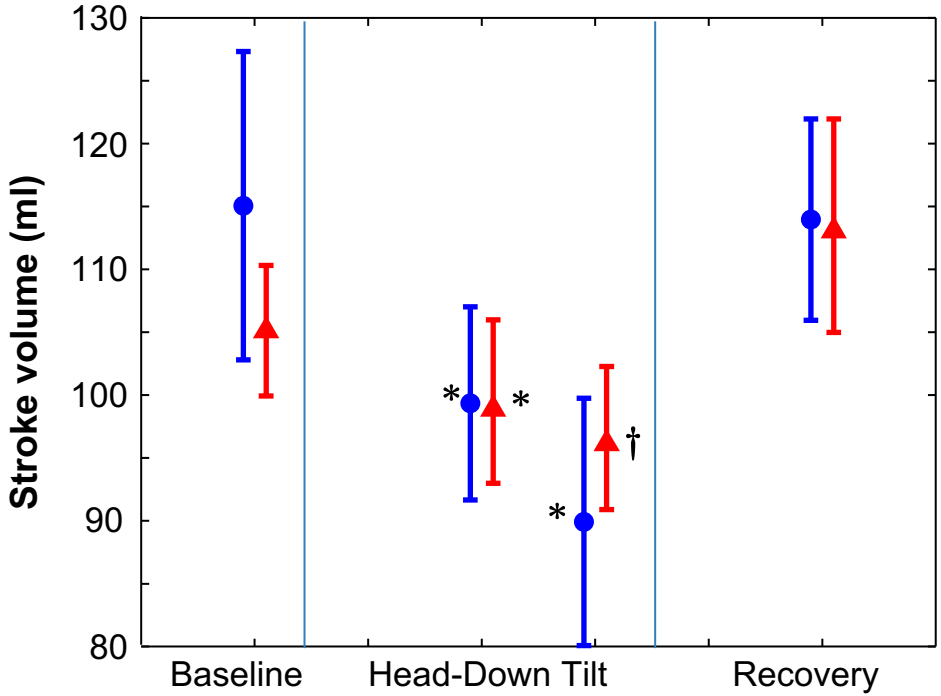
- Supine position
- PC-MRI (3T Biograph mMR)
- Plane at the level of aortic root:
  - Peak flow velocity
- Short-axis stack:
  - Stroke volume
  - Left ventricle mass

3

Results

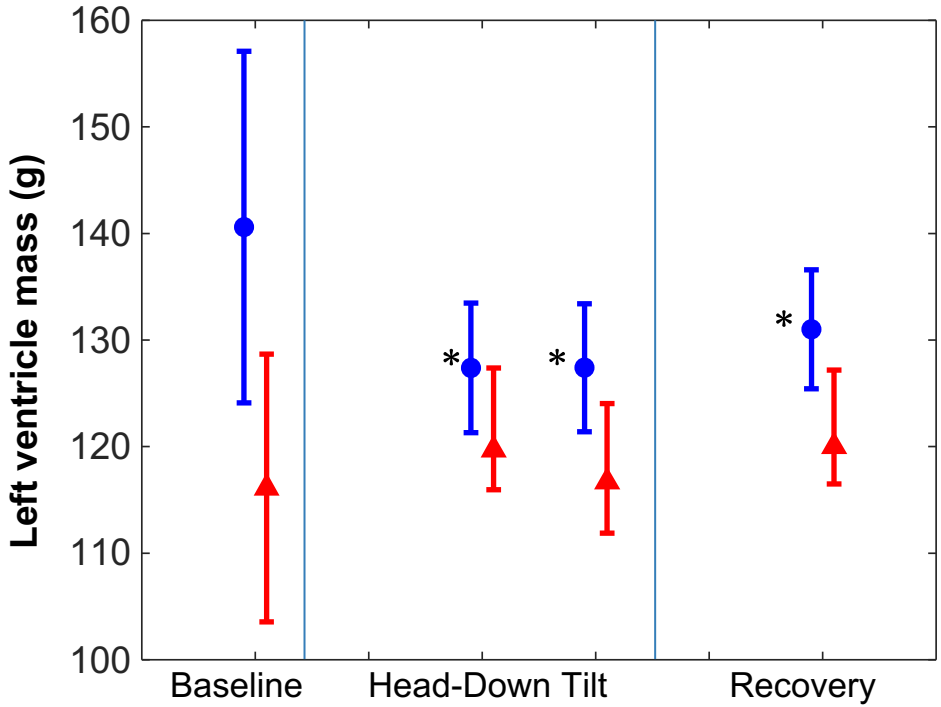
Longitudinal Evolution
Analysis of Covariance
Correlations

Longitudinal Evolution SV



Effect of time* group:
p = 0.005

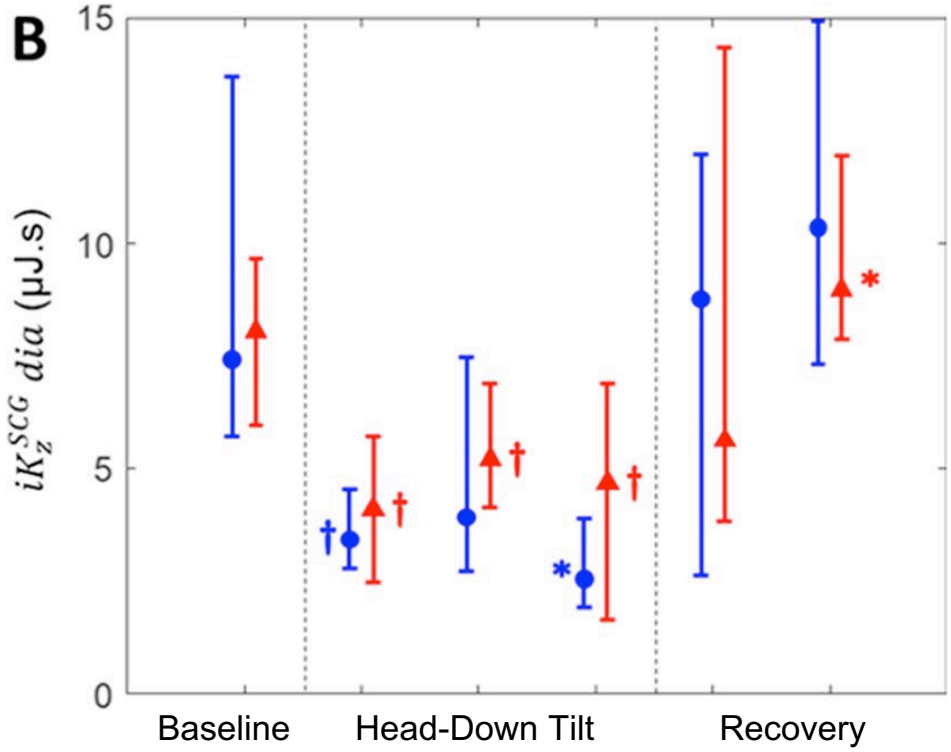
Longitudinal Evolution LV Mass



CTRL
JUMP
* $p < 0.05$
† $p < 0.01$

Non-significant effect of time*group

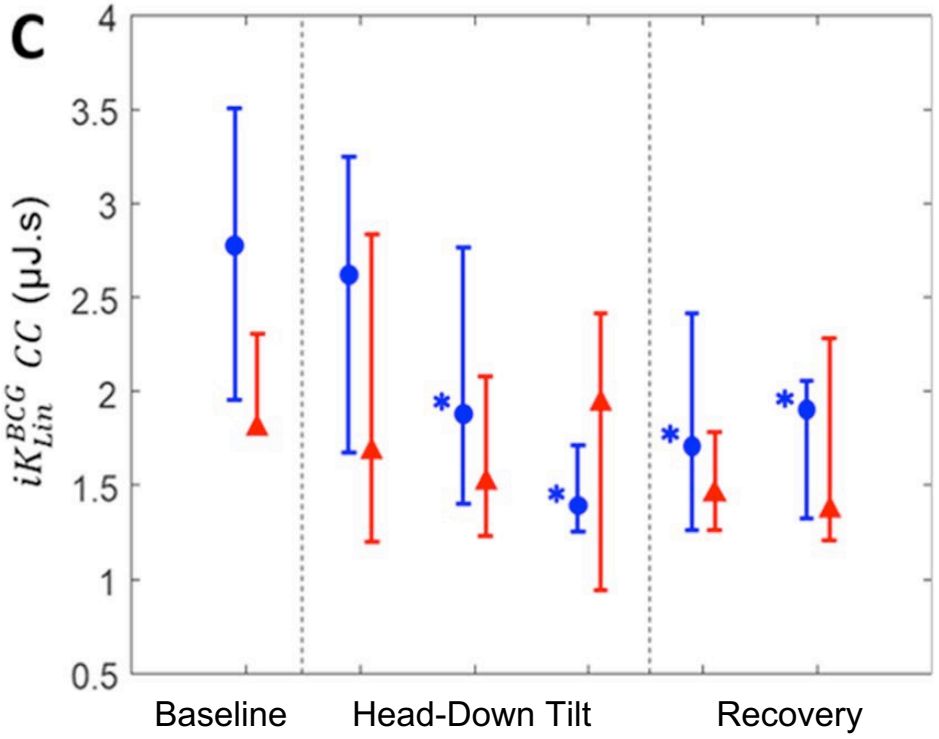
Longitudinal Evolution SCG z



CTRL
JUMP
* $p < 0.05$
† $p < 0.01$

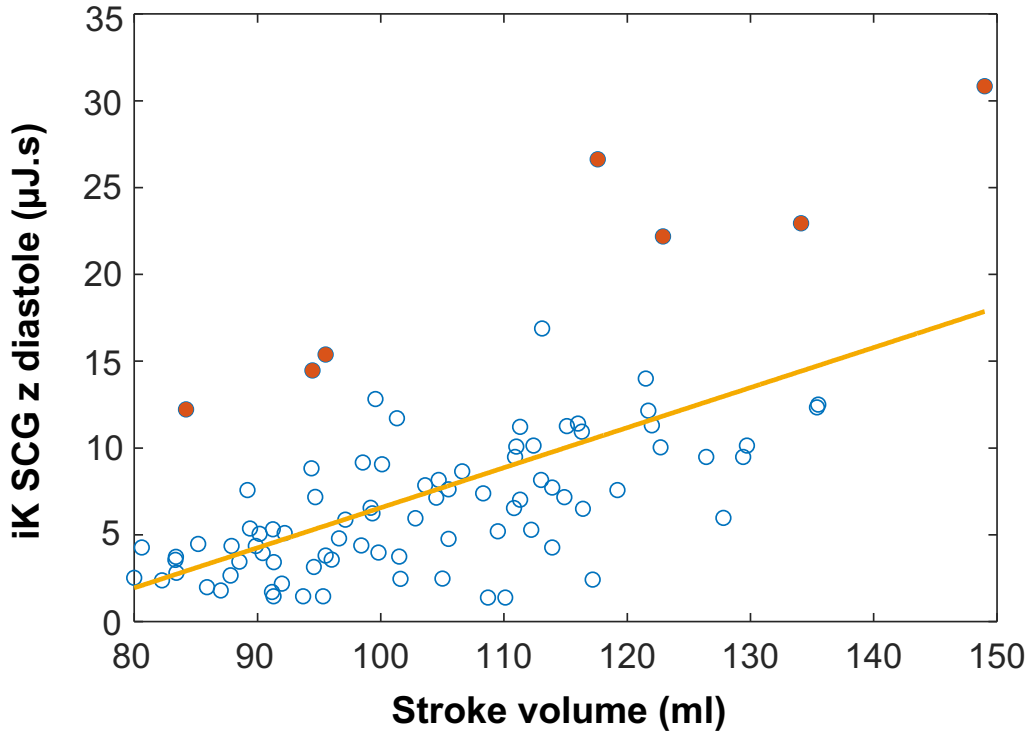
Non-significant effect of time*group

Longitudinal Evolution BCG Lin



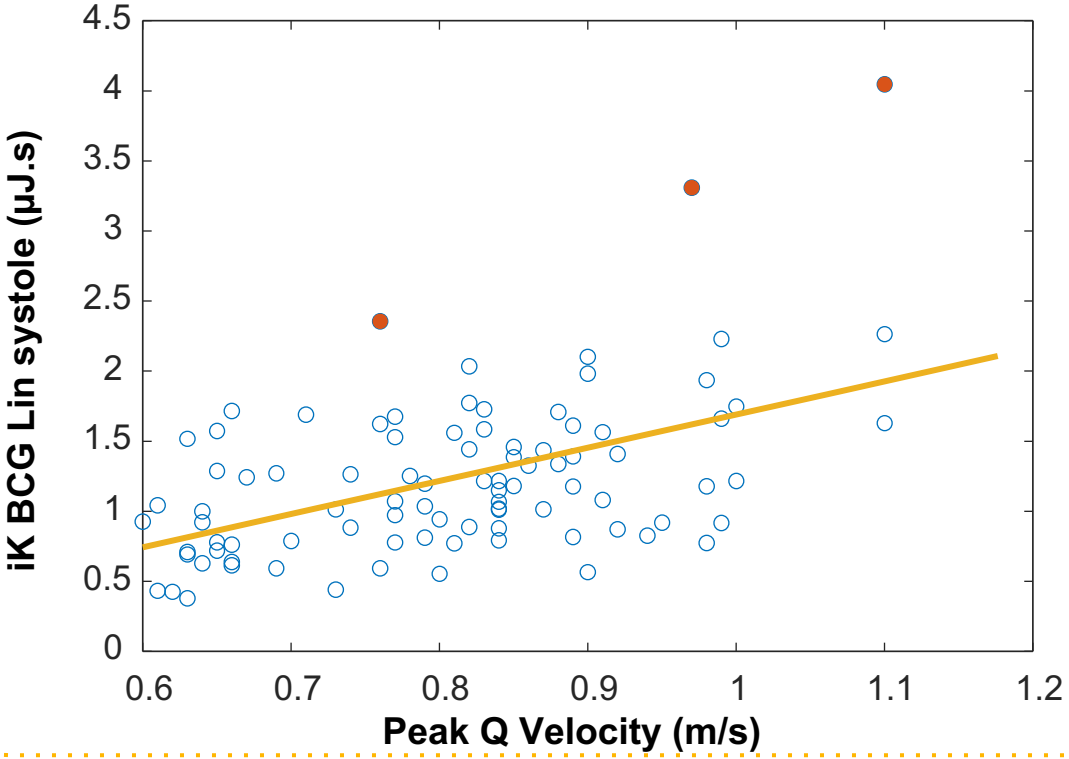
Effect of time*group
p = 0.001

Correlation SCG z vs. SV



$R^2 = 0.39$
$p = 7.0 \times 10^{-11}$

Correlation BCG Lin vs. Flow Velocity



$R^2 = 0.25$
$p = 4.5 \times 10^{-7}$

4

Discussion & Conclusion

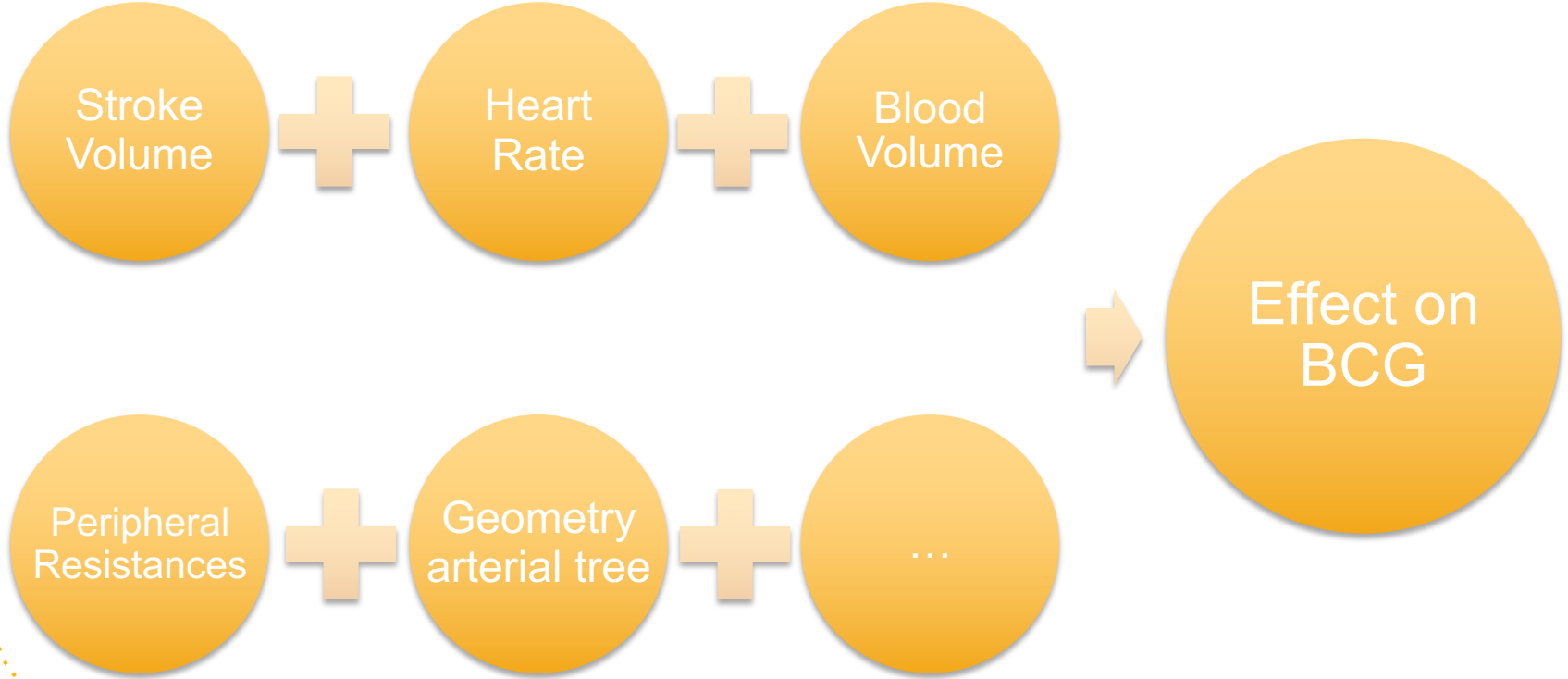
Limitations

- Impact of breathing on SCG & BCG
  - Needs to be further studied on this data set
- Exact position of the sensors (especially on SCG)
  - Possible intra- and inter-subject variations
- Only one degree-of-freedom on the SCG sensor (linear accelerations on z axis)
  - New prototype has 6 degrees-of-freedom for SCG

Limitations

- Not possible to have MRI and BCG measurements at the same time (at least 1 hour between the two records)
- MRI in horizontal position, during breathhold
  - Significant differences on the cardiovascular level

Origin of the BCG signal:



To Sum Up

- BCG and SCG metrics are impacted by long exposure to simulated microgravity
- Effect of countermeasures observed on both MRI (SV) and BCG
- Positive correlations between some BCG/SCG and MRI metrics
- Pathophysiology of BCG & SCG requires further studies

And now?

- Device has been used in space for ~10 years.
- A new user-friendly device will follow, to try and confirm encouraging results to evaluate cardiorespiratory fitness among astronauts.
- A start-up based on this technology has been created (HeartKinetics). They developed an app to record SCG with a smartphone.
- Applications in the diagnostic and monitoring of heart failure, valvulopathies, etc.

Thank you!

- **Team**
  - Dr. Pierre-François Migeotte

  - Ir. Amin Hossein

  - Ir. Damien Gorlier

- **PhD Supervisors**
  - Pr. Benoît Haut
  - Pr. Philippe van de Borne

- **Collaborators**
  - Pr. Jens Tank (DLR)
  - Dr. Irina Funtova (IBMP)
  - Dr. Elena Luchitskaya (IBMP)
  - Pr. Enrico G. Caiani (Politecnico di Milano)
  - Federica Landreani (Politecnico di Milano)
  - Roberta Egoriti (Politcnico di Milano)

- **Volunteers of the ESA-RSL study**

- **Staff and team at DLR**

LPHYS TIPs ULB UNIVERSITÉ LIBRE DE BRUXELLES POLITECNICO MILANO 1863 DLR Belgian Science Policy Office belspo fnrs LA LIBERTÉ DE CHERCHER esa

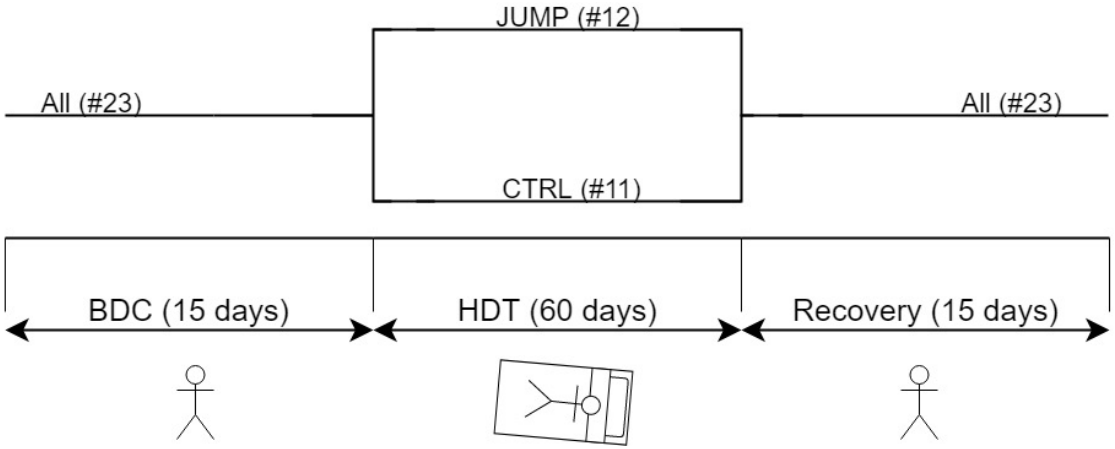
Thank you!

[beep] Houston, are there any questions?

You can contact me at jeremy.rabineau@ulb.be, on Research Gate, or on LinkedIn

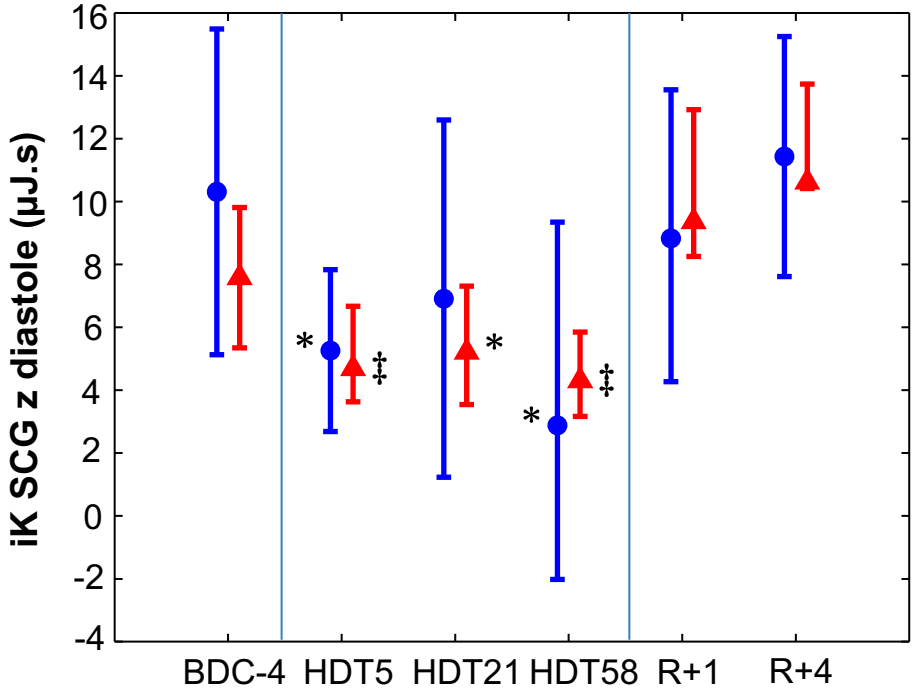
Backup Slides

Groups and Schedule



Group	N	Age (year)	Weight (kg)	Height (cm)	BMI (kg/m²)	BSA (m²)
CTRL	11	28 ± 6	180 ± 6	76 ± 8	23.5 ± 2.2	1.9 ± 0.1
JUMP	12	30 ± 7	182 ± 5	78 ± 7	23.4 ± 1.7	2.0 ± 0.1

Longitudinal Evolution SCG z

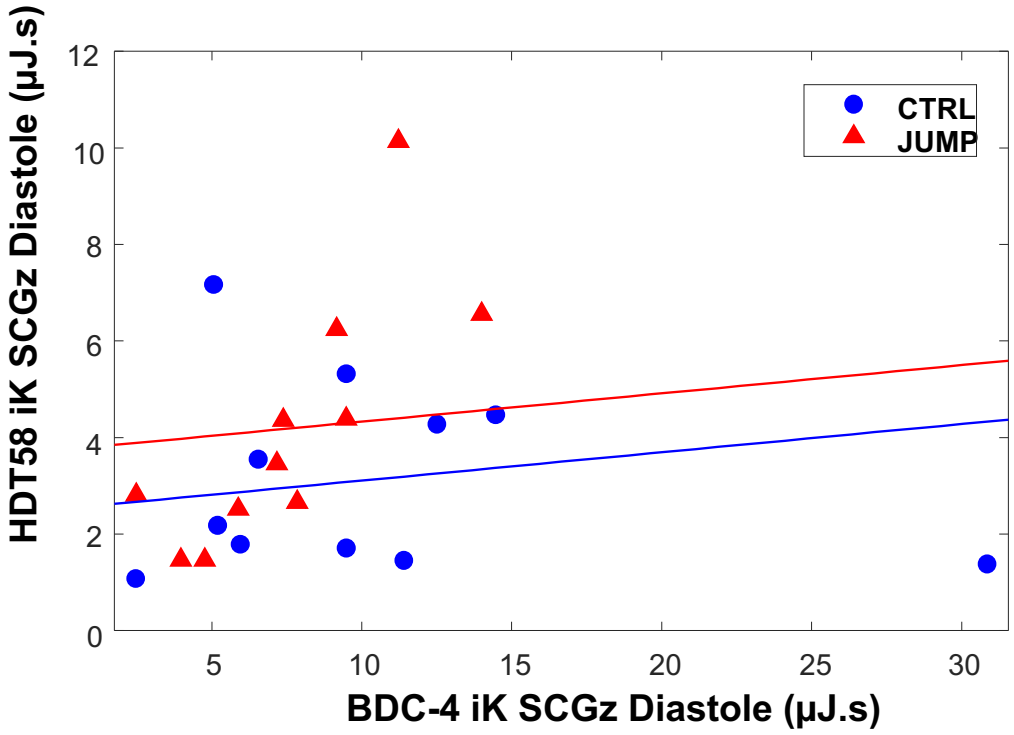


CTRL
JUMP
* $p < 0.05$
† $p < 0.01$
‡ $p < 0.001$

Comparison with baseline

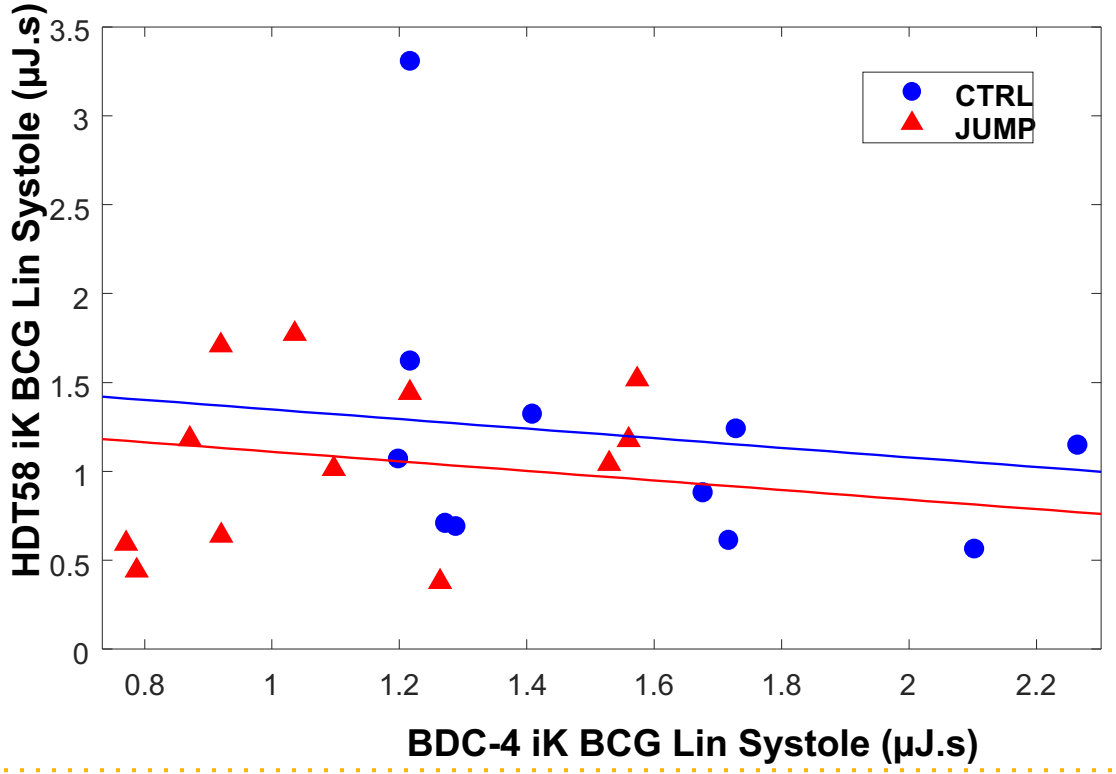
ANCOVA SCG z

Inter-group Delta: 1.2 µJ.s
p = 0.25



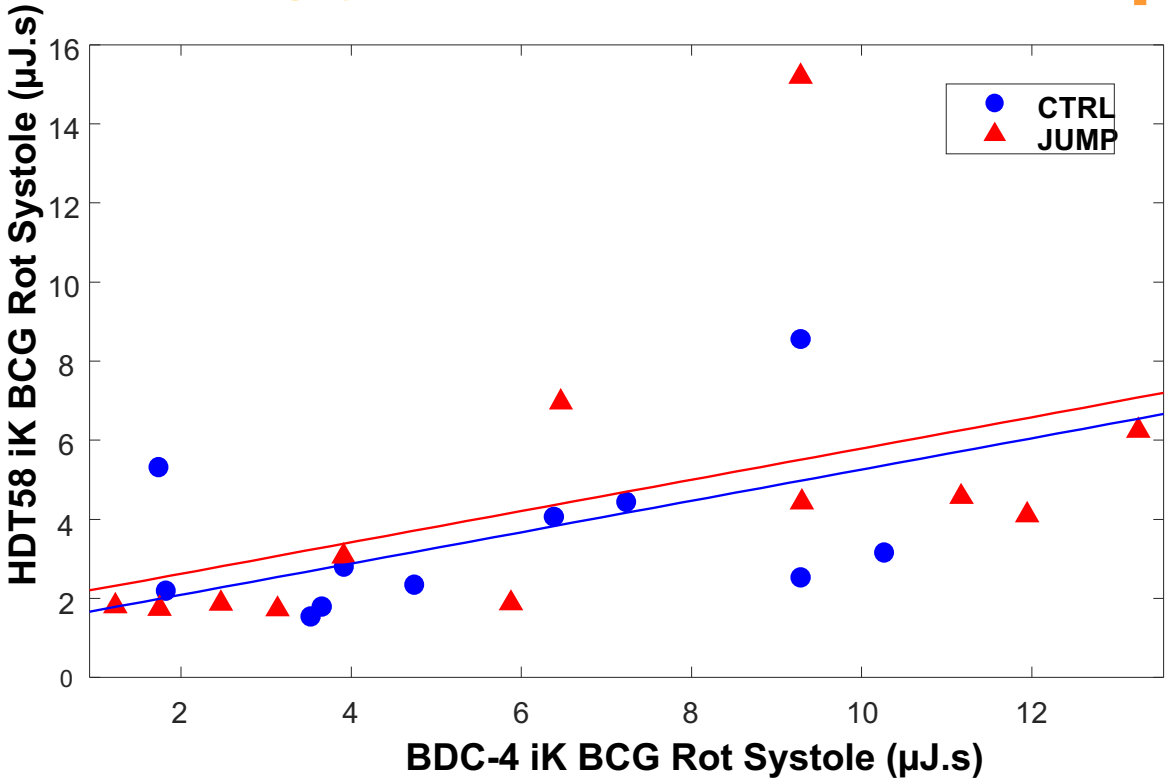
ANCOVA BCG Lin

Inter-group Delta: -0.24 µJ.s
p = 0.47



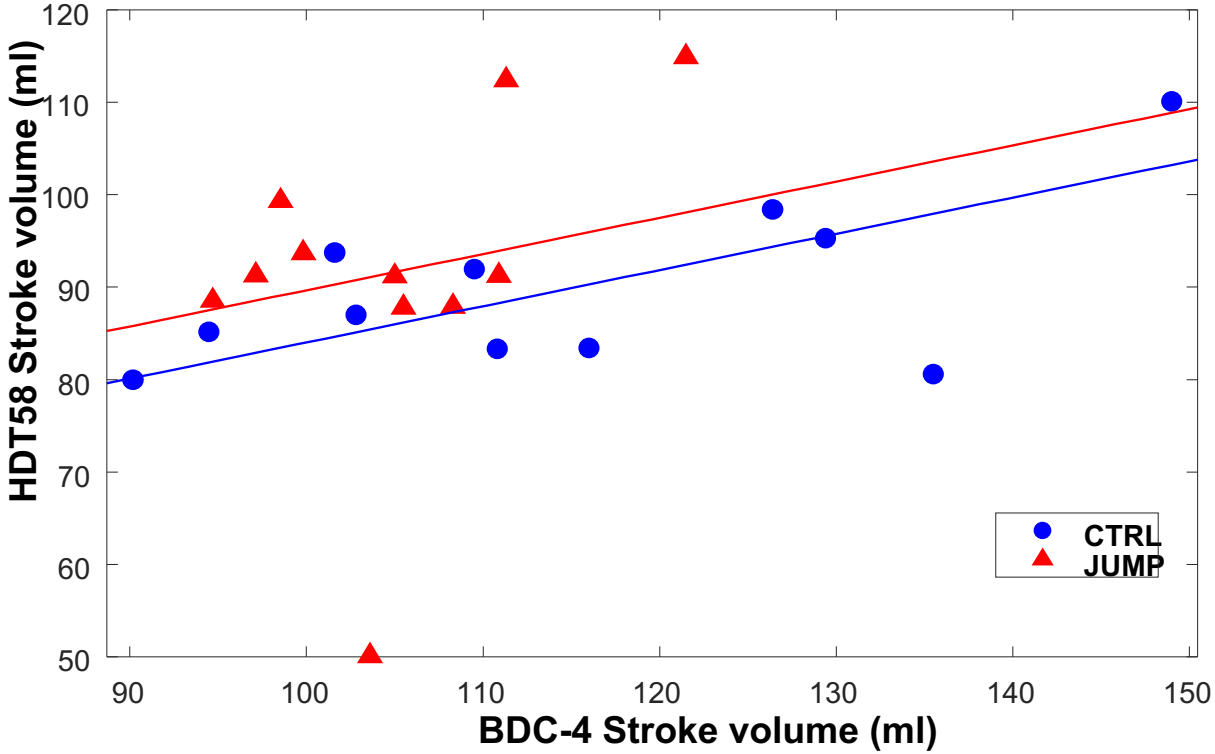
ANCOVA BCG Rot

Inter-group Delta: 0.53 µJ.s
p = 0.66



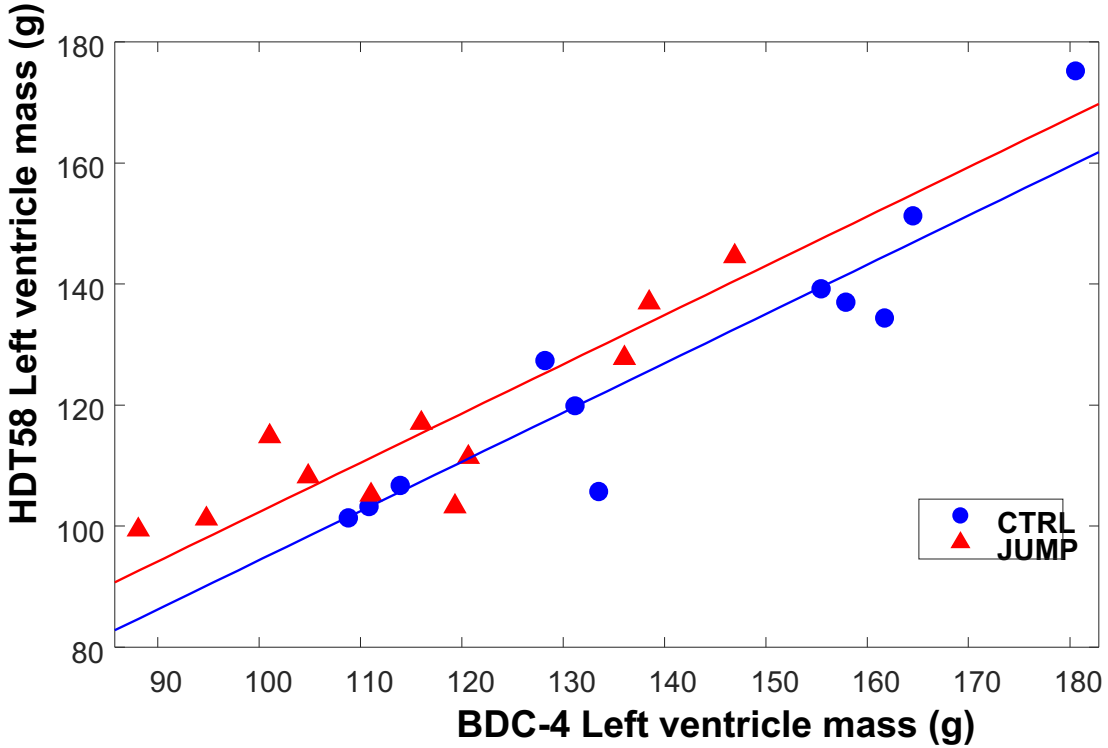
ANCOVA SV

Inter-group Delta: 5.6 ml
p = 0.046



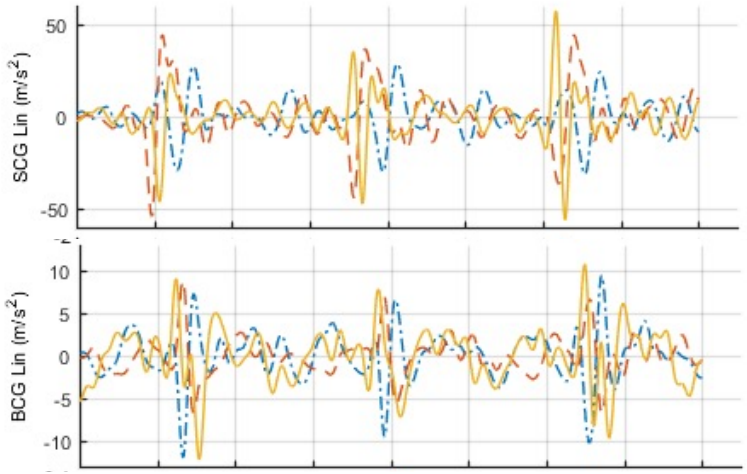
ANCOVA LV Mass

Inter-group Delta: 8.0 g
p = 0.066

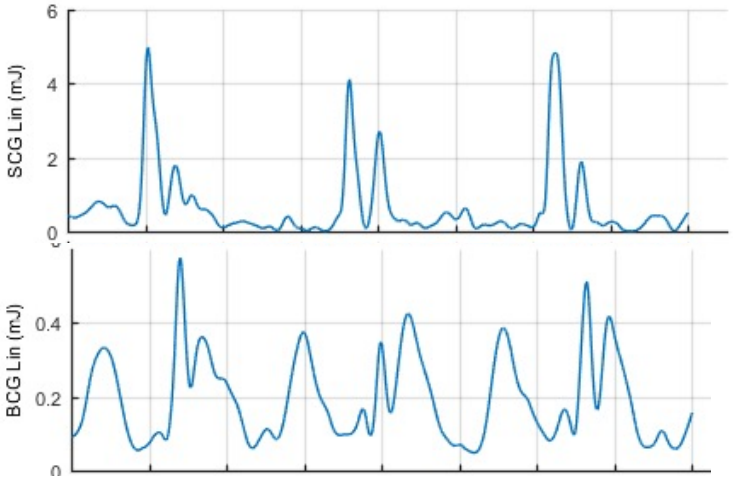


Equations Kinetic Energy

$$K_{lin} = \frac{1}{2} m(v_x^2 + v_y^2 + v_z^2)$$



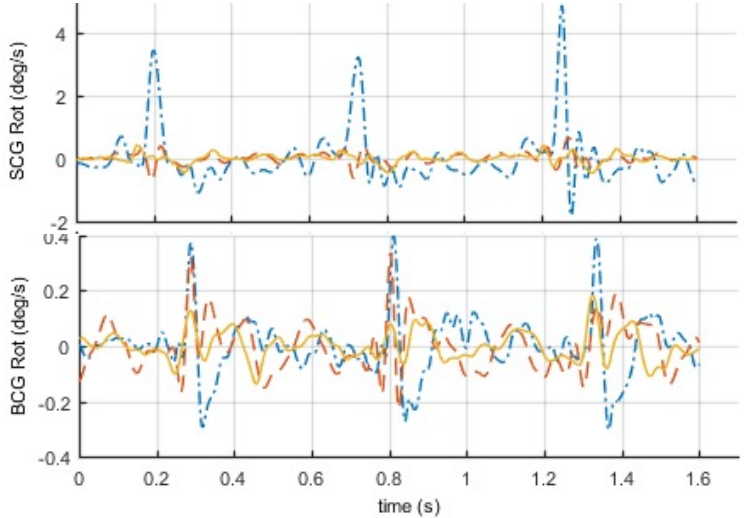
Accelerations (3 axes)



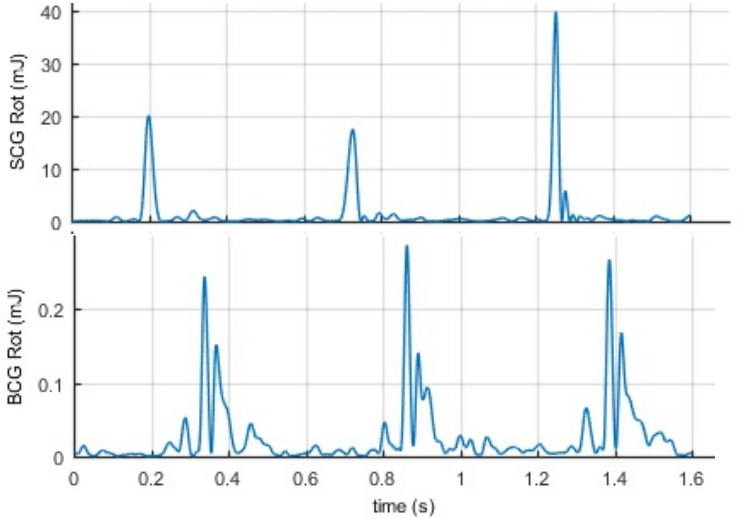
Kinetic Energy (1 signal)

Equations Kinetic Energy

$$K_{rot} = \frac{1}{2}(I_{xx}\omega_x^2 + I_{yy}\omega_y^2 + I_{zz}\omega_z^2)$$

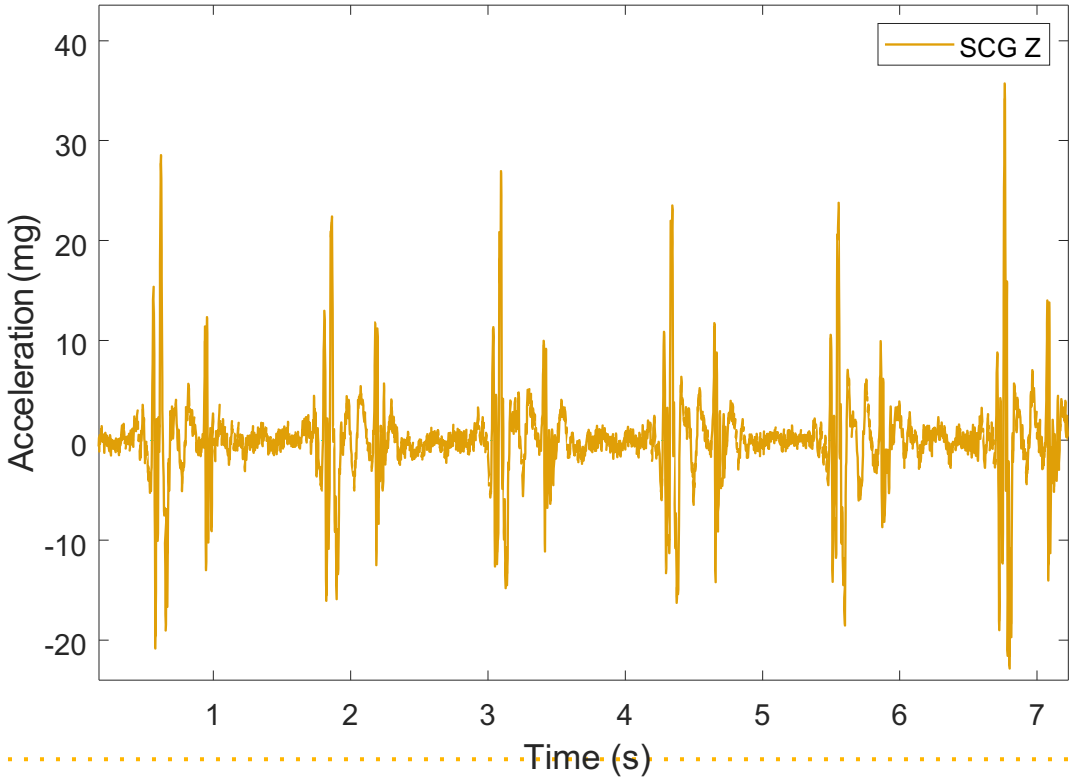


Angular Velocity (3 axes)

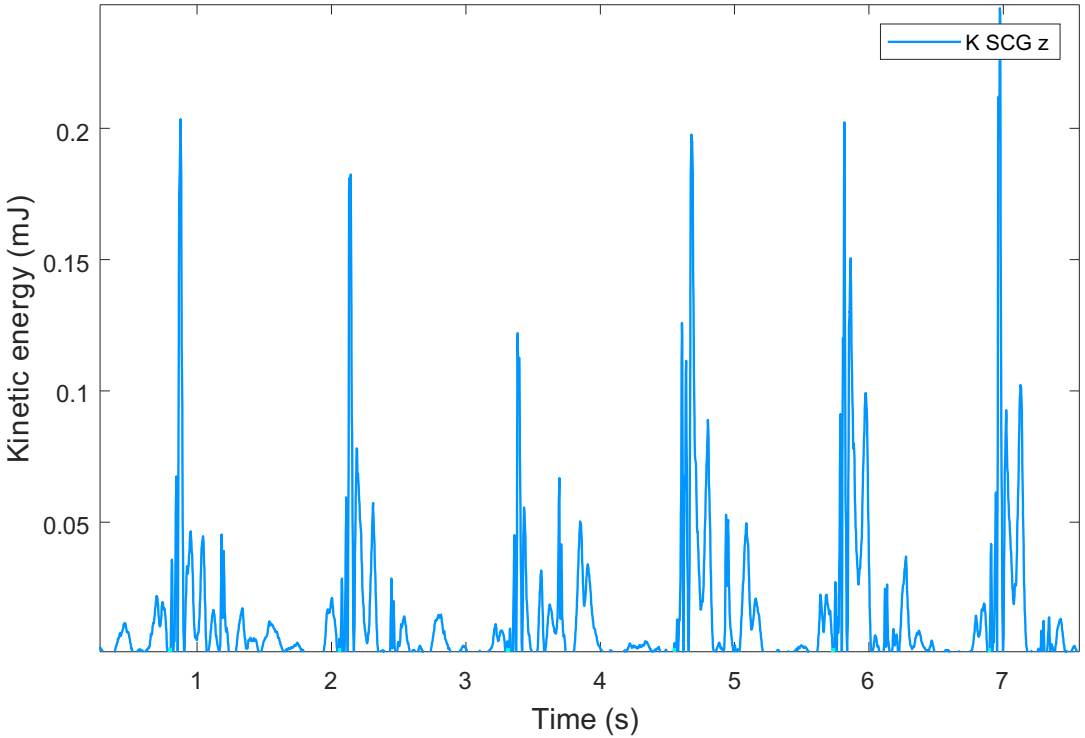


Kinetic Energy (1 signal)

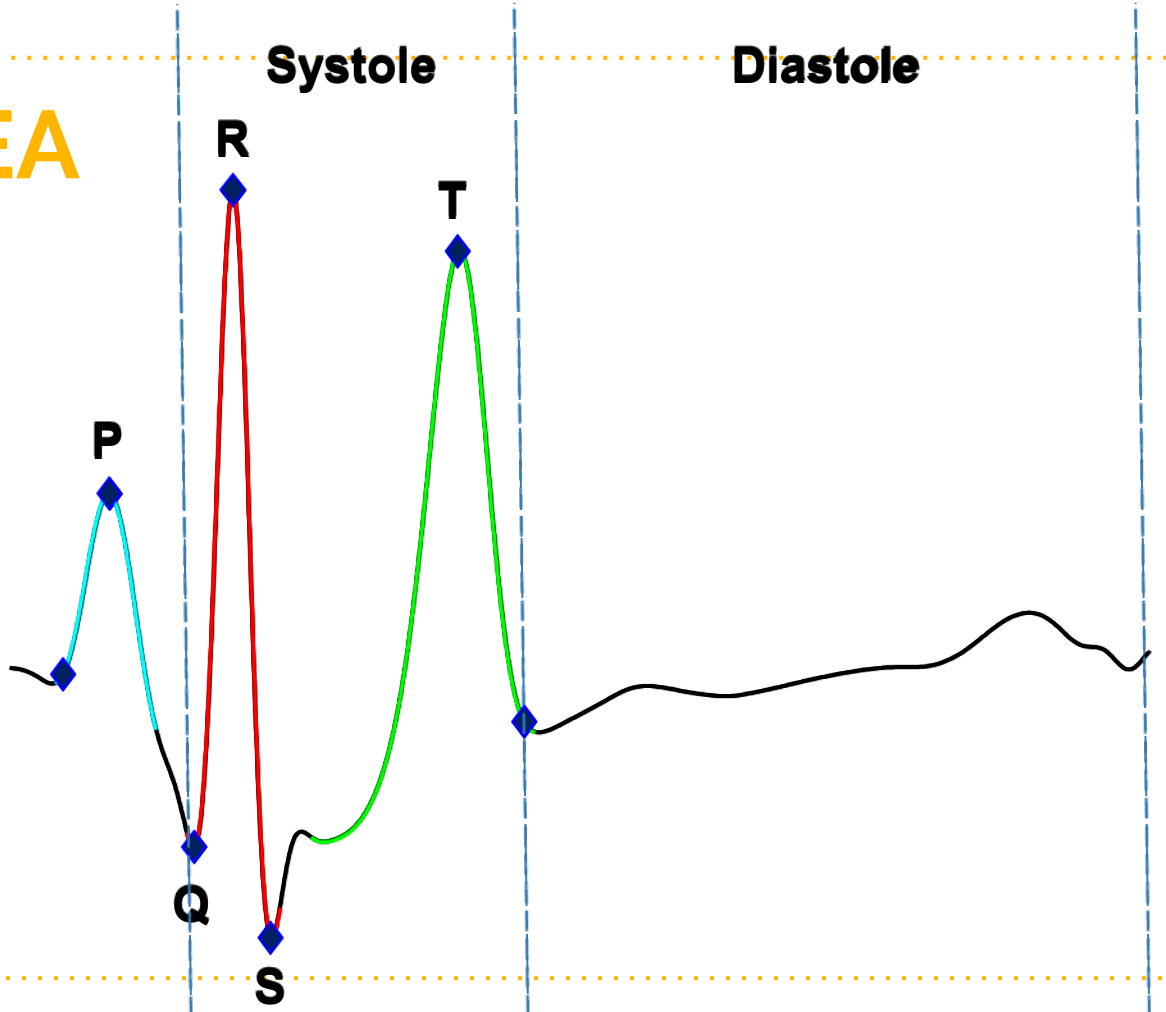
SCG z Signal



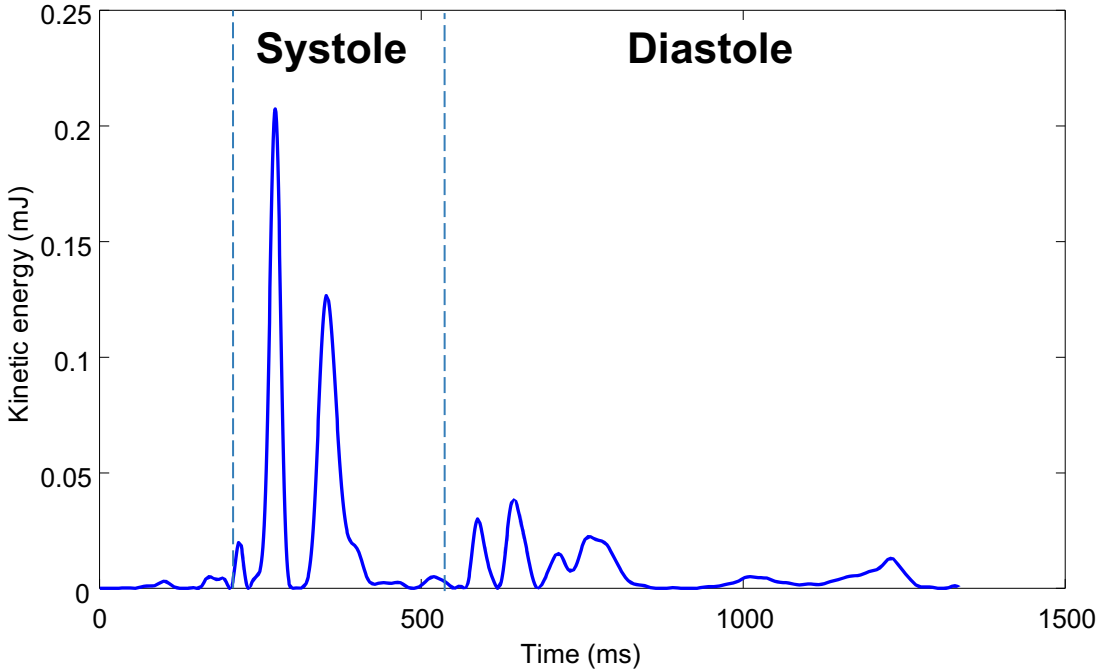
K SCG z Signal



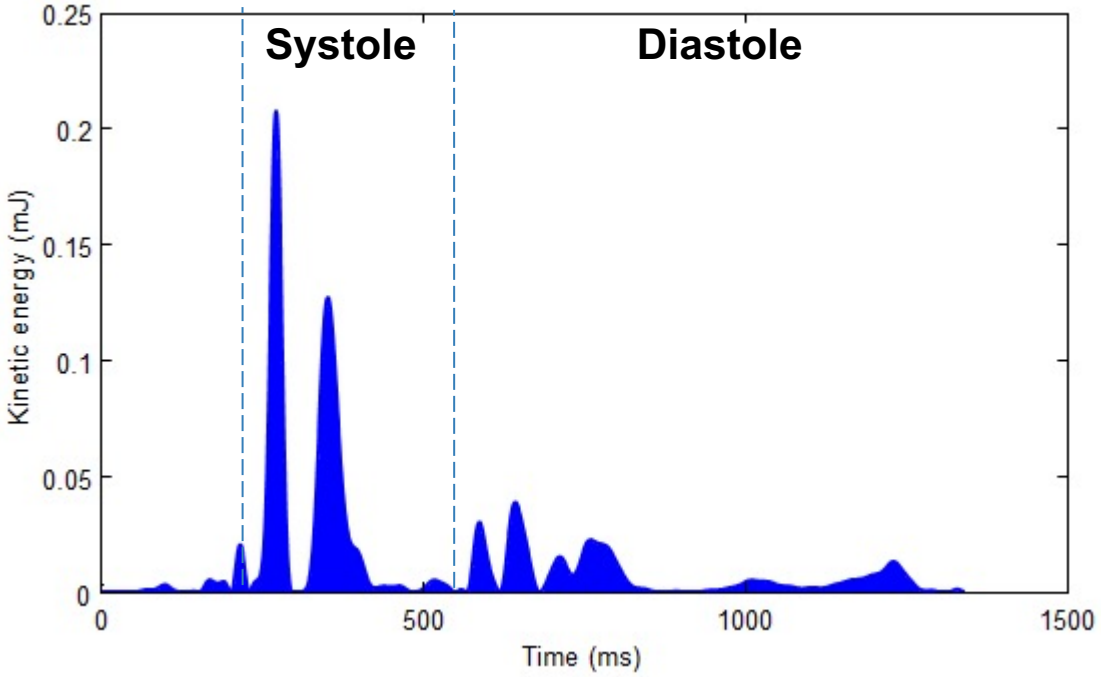
ECG EA



K SCGz EA


Systole
Diastole
Kinetic energy (mJ)
Time (ms)
0.25
0.2
0.15
0.1
0.05
0
0
500
1000
1500

K SCGz EA


Systole
Diastole
Kinetic energy (mJ)
0.25
0.2
0.15
0.1
0.05
0
0
500
1000
1500
Time (ms)