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# Standing Ballistocardiography Measurements in Microgravity

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Corey McCall

Zachary Stuart; Richard M. Wiard, PhD; Omer T. Inan, PhD;
Laurent Giovangrandi, PhD; C. Marsh Cuttino, MD;
Gregory Kovacs, MD/PhD

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STANFORD Transducers Lab

# Overview

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**Aim:** A compact self-use medical device for astronauts to monitor cardiovascular deconditioning in **multi-g environments**.

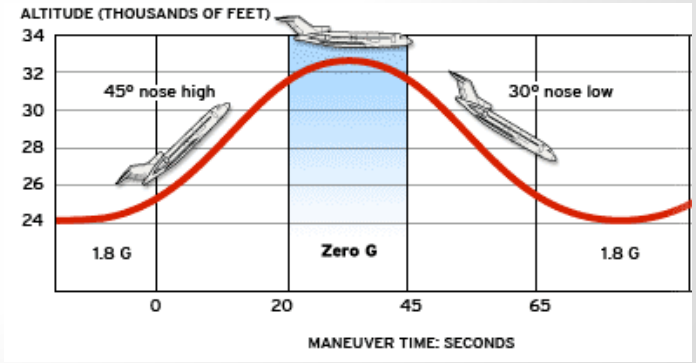
- Earth (baseline)
- Interstellar space stations
- Smaller shuttles and capsules
- Lunar or Martian bases

**Experiment:** Compare BCG weighing scale in microgravity to ground and free-floating measurements.

- Scale-based BCG is well characterized clinically on Earth for cardiac output change, cardiac contractility, heart failure, and athletic performance.
- Longitudinal BCG using a scale with foot bindings is easier to measure than free-floating methods in multi-g environments.

**Parabolic Flight Testing**

- Phase 1: Hardware proof of concept, 2012.
- Phase 2: Multi-subject characterization, 2013. (Today's talk)
- Phase 3: Addition of PWV (arterial stiffness), 2014.



# Scale-based BCG in Microgravity

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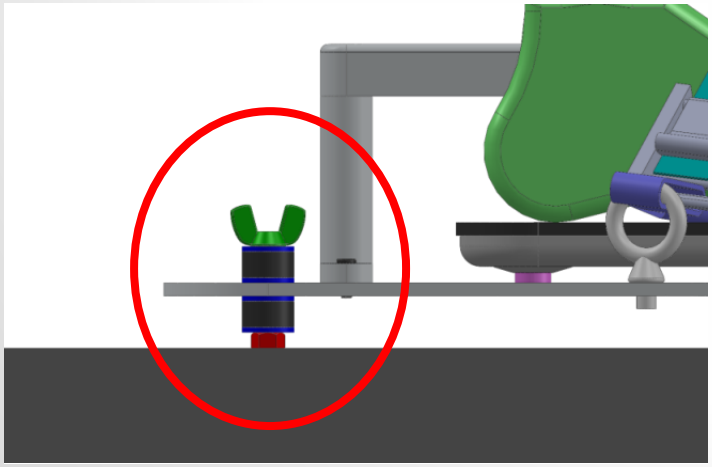
Scale-based BCG

Scale preloaded and attached to mounting plate



Mounting plate attached to aircraft with vibration-isolating viscoelastic washers

# Scale-based BCG in Microgravity

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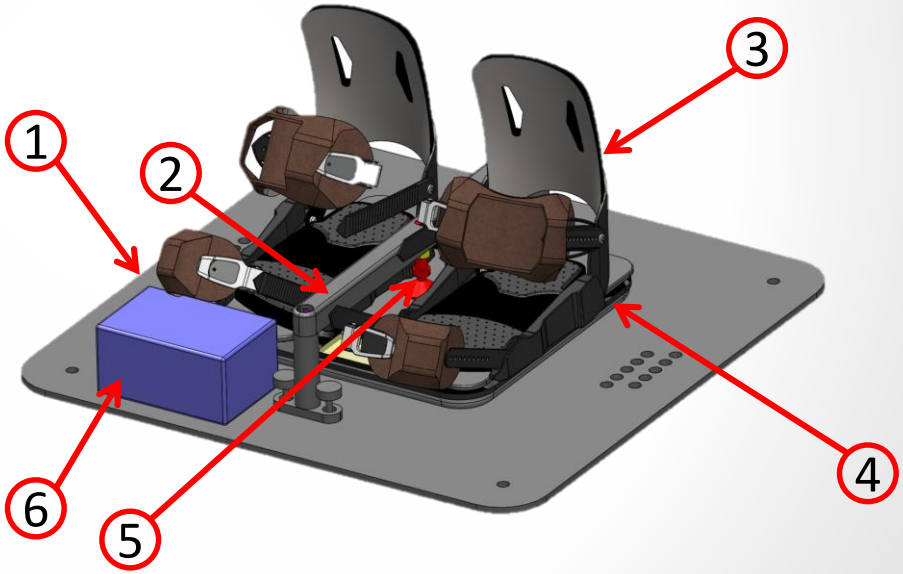
1) ¼-inch aluminum plate (24” x 24”)
2) Bolted stanchions with crossbar
3) Foot strap assembly w/quick release
4) BCG scale (preloaded 10-20 lbs)
5) Threaded swivel leveling mount w/tightening nut
6) Electronics enclosure

Foot binding assembly




Complete BCG scale assembly adapted for microgravity

# Experiment

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**Equipment:**

- BCG scale assembly
- Wearable 3D accelerometer taped to lower lumbar region of back
- Custom analog electronics (ECG, scale BCG, accelerometer BCG)
- Wearable data acquisition unit with real-time Bluetooth streaming to laptop
- Boeing 727-200 aircraft (Zero-G Corp.)

Accelerometer placement

**Protocol:**

- Lay down on floor during hypergravity transitions.
- Float up to standing position for scale-based BCG (~17 sec).
- Controlled free-floating accelerometer-based BCG captured for reference (~17 sec).
- Ground BCG recordings for baseline (~20 sec).


Wearable Electronics Box

**Population:**

- 6 healthy males (ages 20-56, mean 38)
- 4 healthy females (ages 19-40, mean 27)

# Experiment

Transitioning to zero-G for scale-based BCG measurement

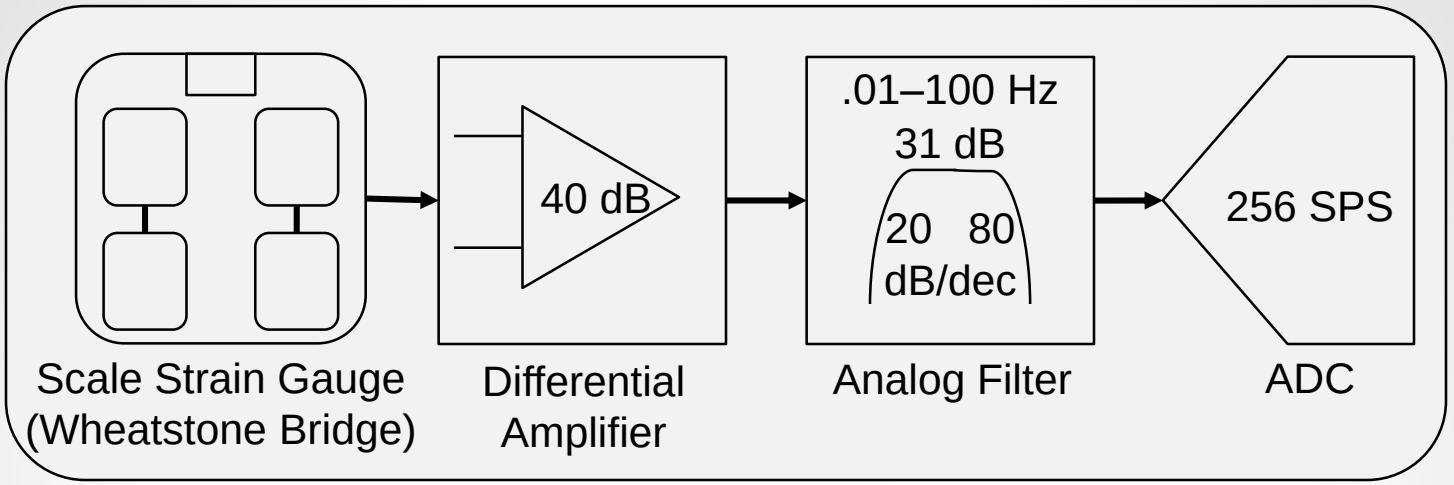
Measurement position

# Experiment

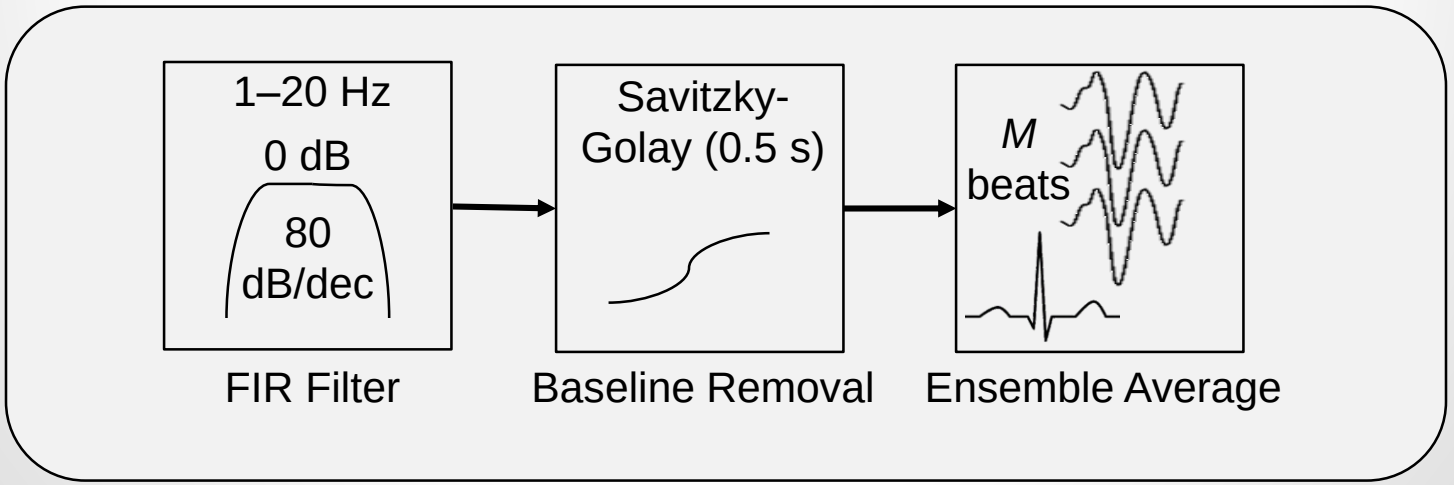



Controlled free-floating for accelerometer-based BCG measurement

# Signal Processing

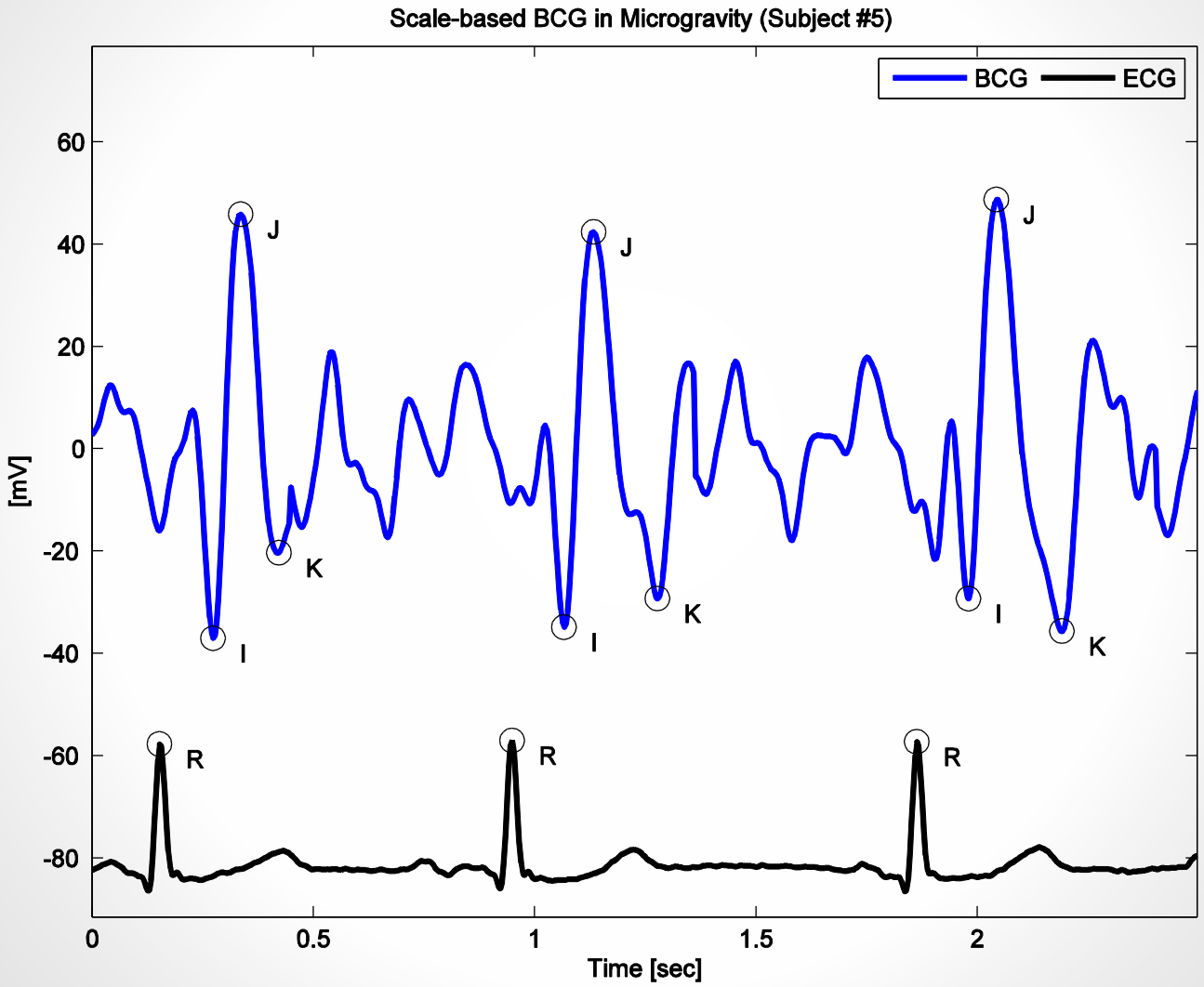



Hardware signal chain




Post-processing signal chain

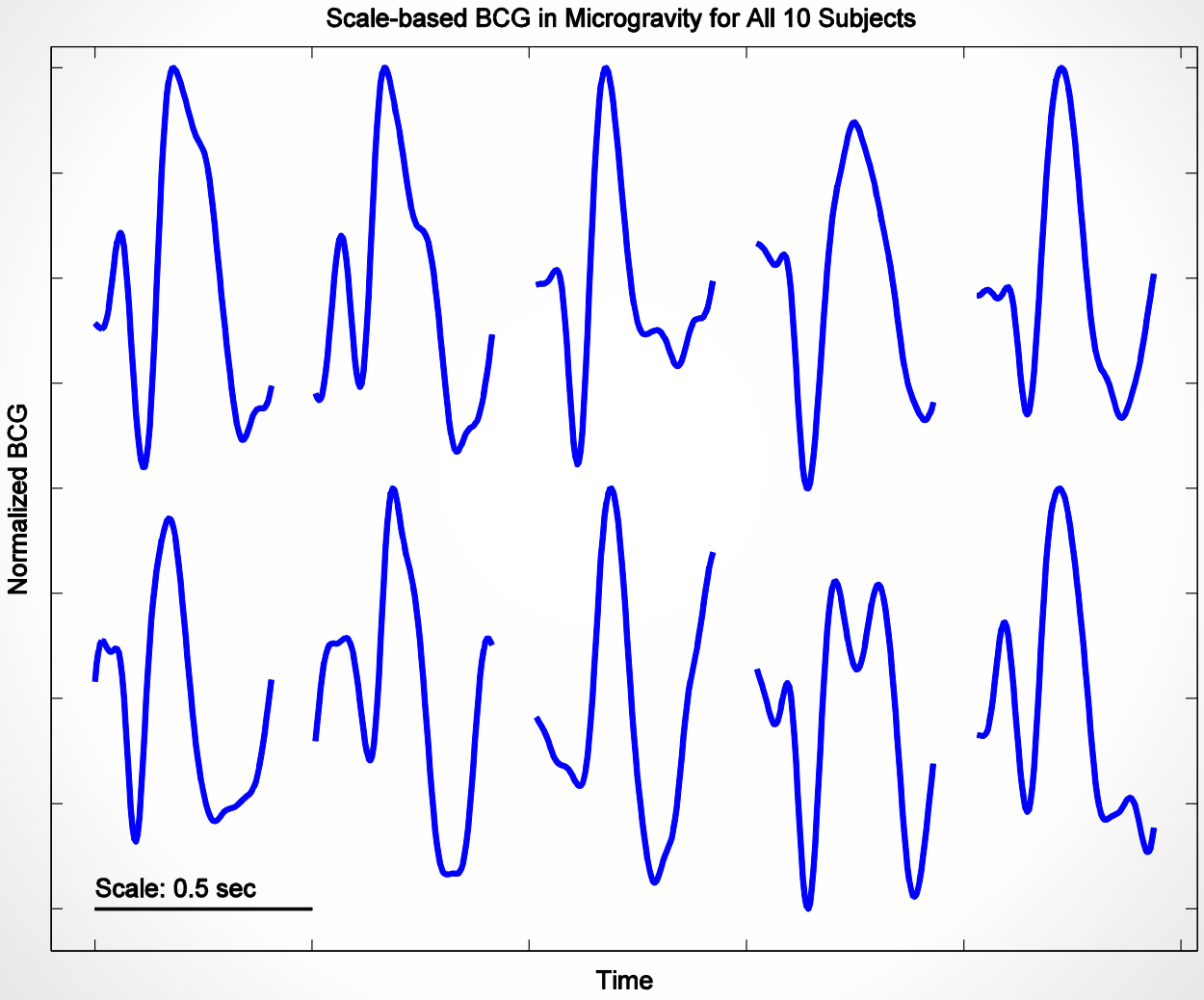
# Results




Typical scale-based BCG in microgravity for $M$ = 6 adjacent beats

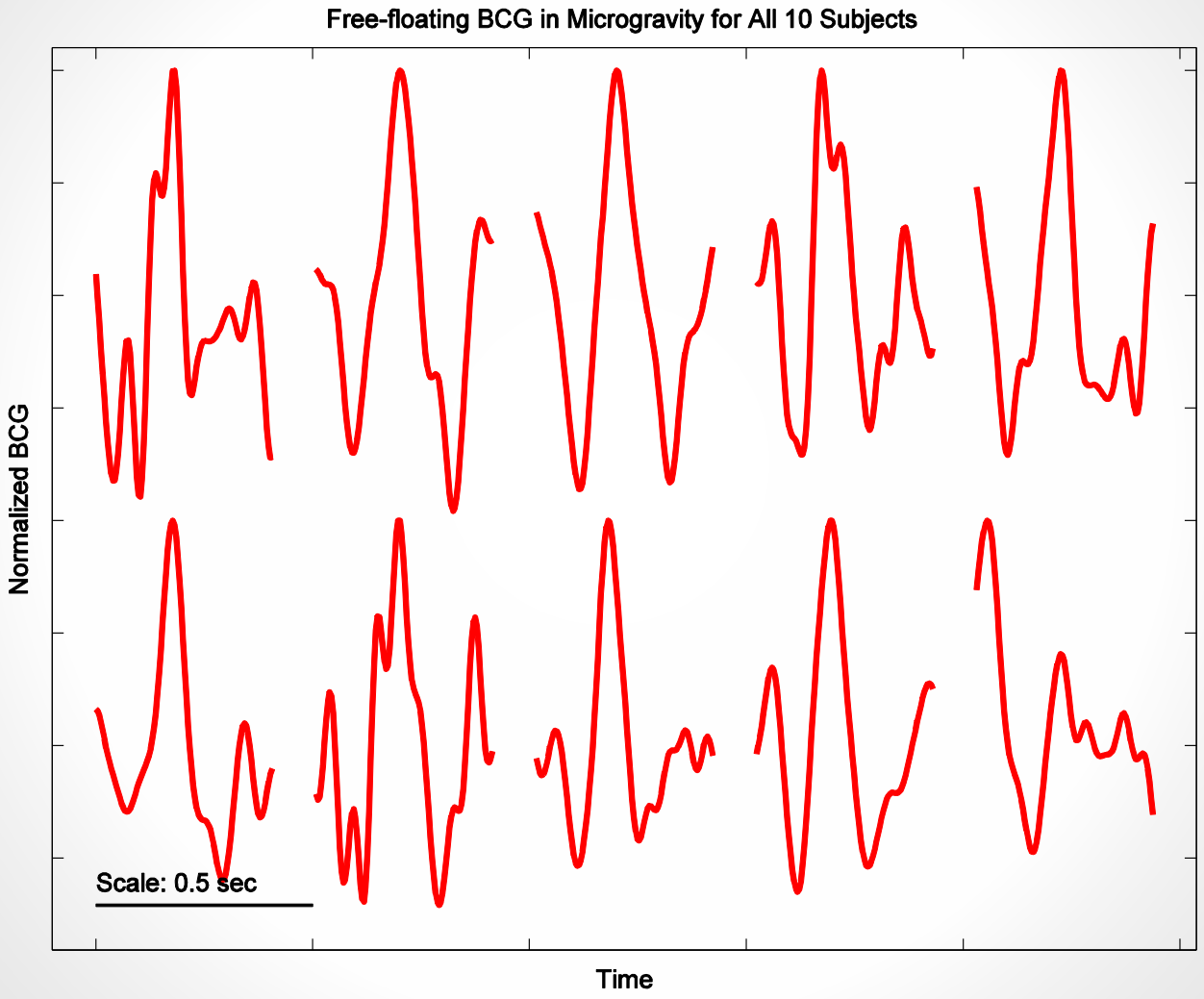
# Results





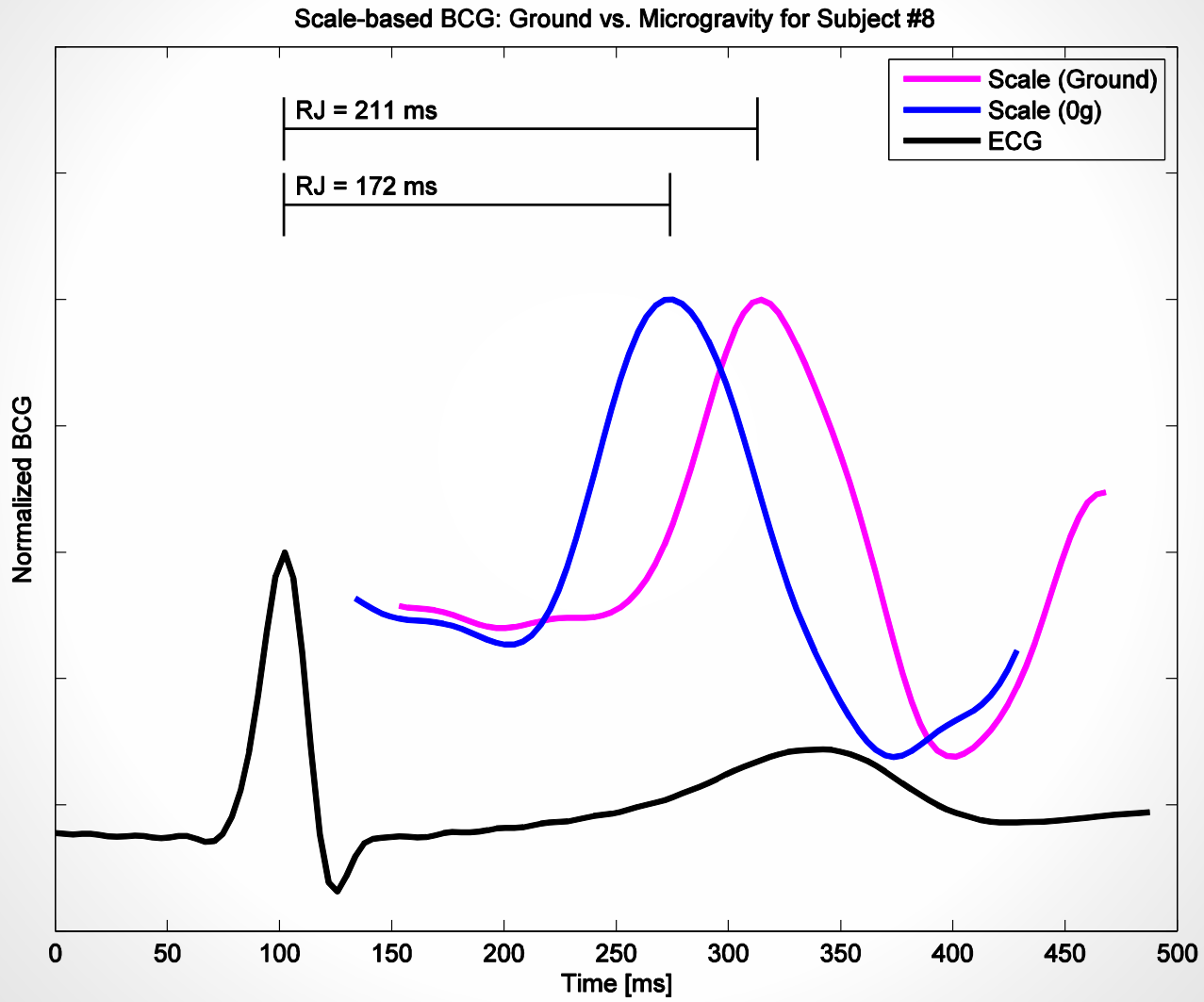

Scale-based BCG dataset (Mean *M* = 148 beats)

# Results



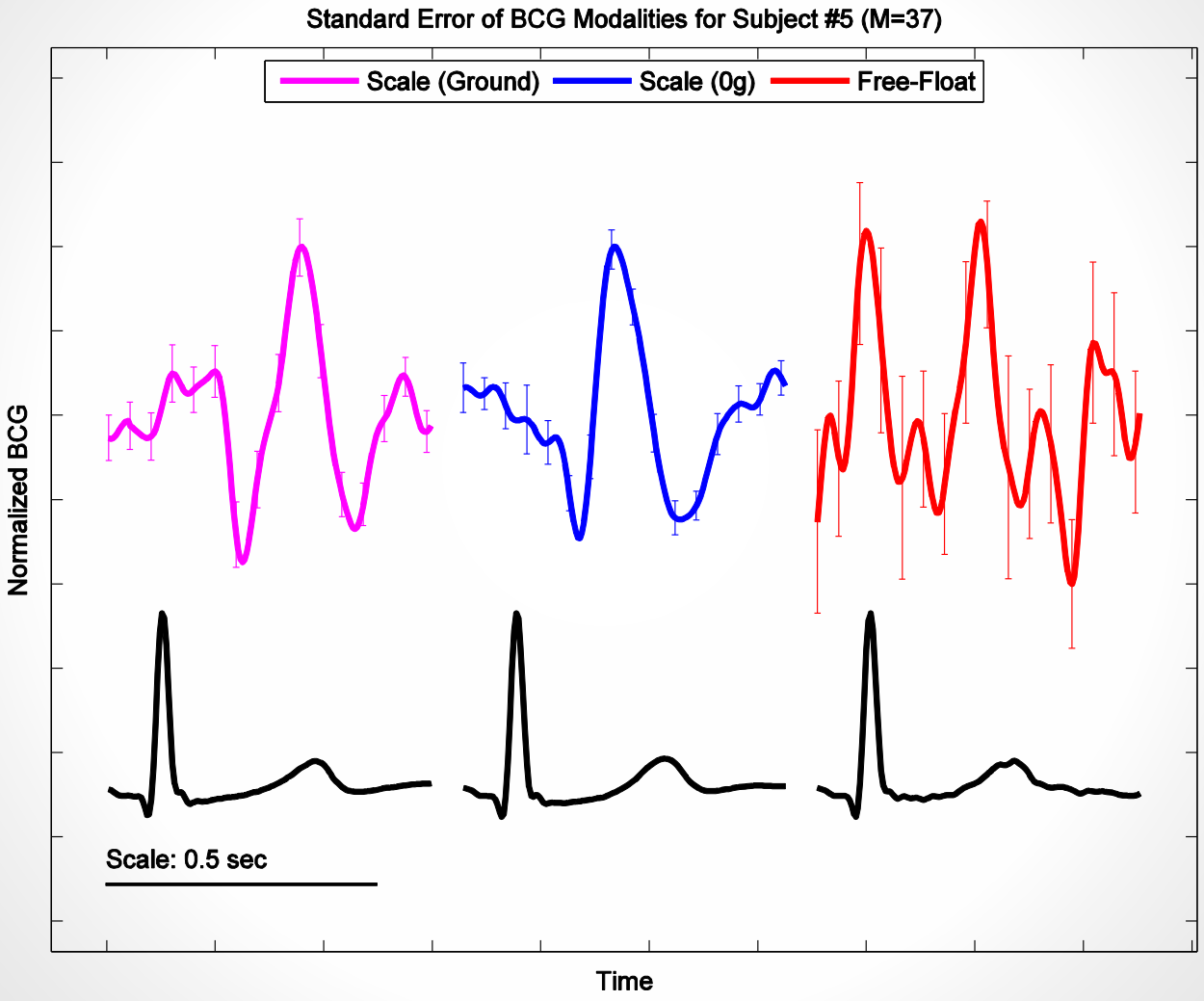

Free-floating BCG dataset (Mean *M* = 40 beats)

# Results




RJ interval timing for typical subject

# Results




Standard error of BCG ensemble average for typical subject

# Key Findings

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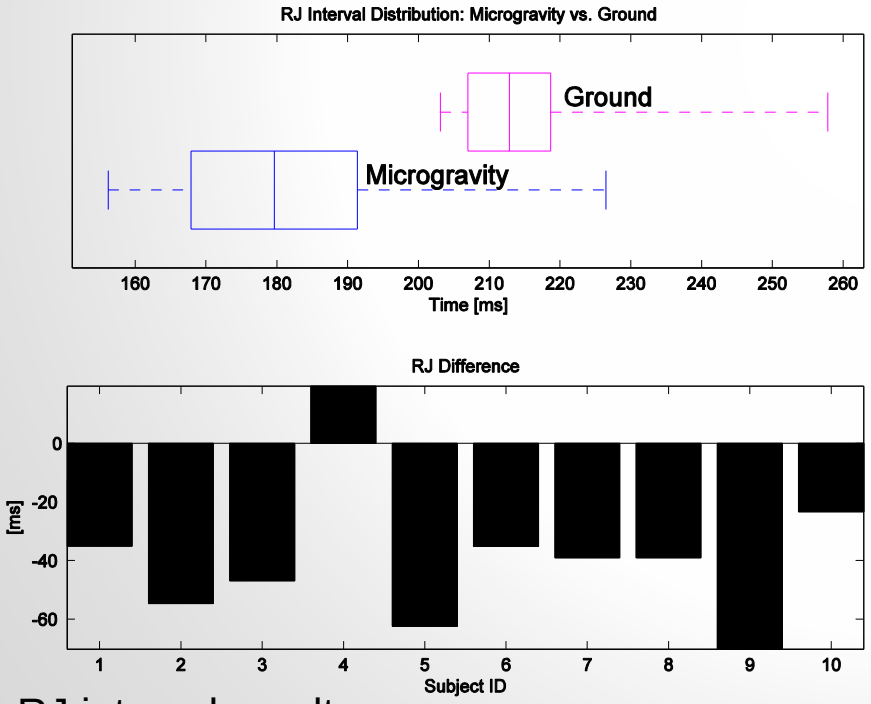
## RJ Interval:

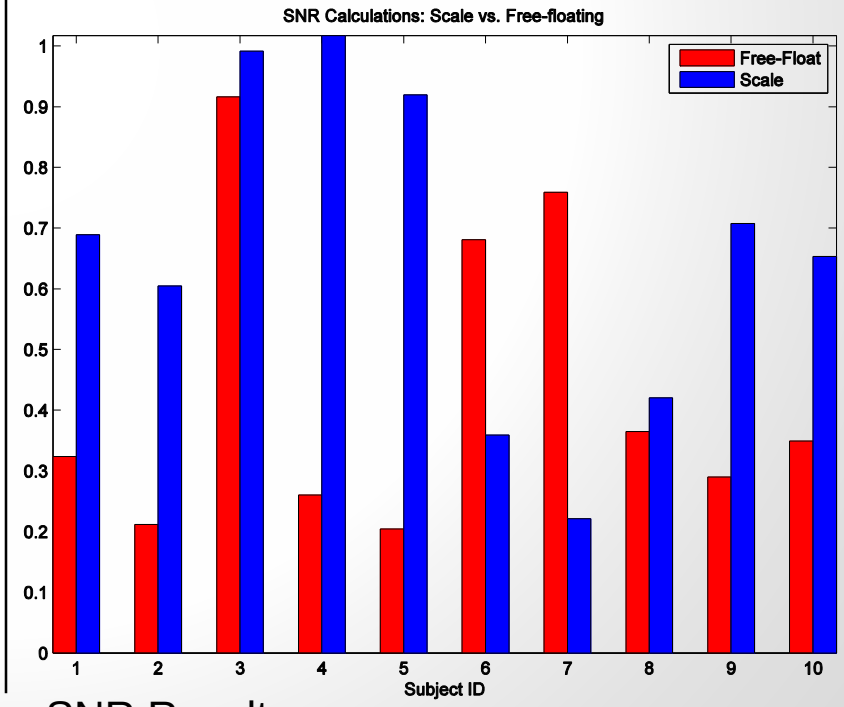
Average of **38.7 ms RJ interval decrease** from ground to microgravity scale-based BCG measurements ($P < 0.001$). This is consistent across 9 of 10 test subjects.

## SNR (sample correlation coefficient method):

Average of **2.08 (6.34 dB) SNR increase** from free-floating to scale-based microgravity BCG measurements. This is consistent across 8 of 10 test subjects.




RJ interval results




SNR Results

# Conclusions

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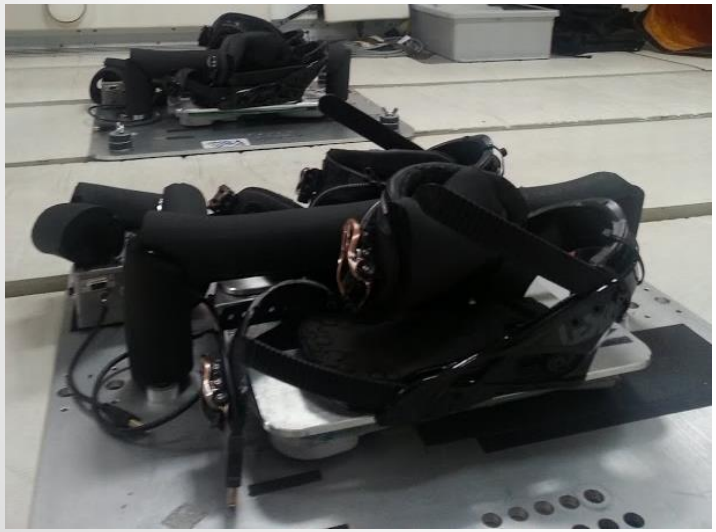
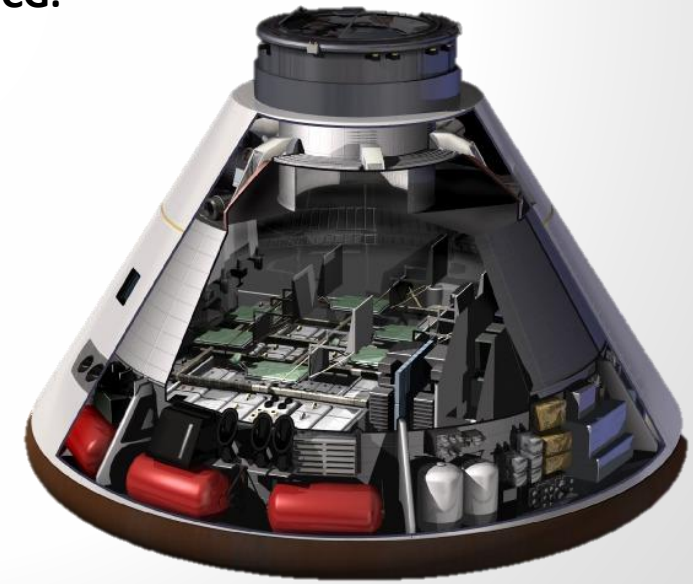
- **Multi-g BCG measurement was demonstrated in microgravity and on the ground with a modified BCG weighing scale.**
- **BCG scale design eliminates the need to free-float without disturbance, enabling measurements in smaller cabin volumes like space capsules.**
- **In 9 of 10 subjects, the RJ interval was shown to decrease significantly in microgravity vs. ground measurements, possibly due to the transient increase in venous return, and consequent decrease in pre-ejection period, experienced during microgravity.**
- **In 8 of 10 subjects, the SNR of scale-based measurements in microgravity was higher than free-floating measurements, indicating that a scale-based approach may be a quality alternative to accelerometer-based free-floating BCG.**





# Thank You!

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**Flight Opportunities, Solicitation NOCT-110**


**Reduced Gravity Office, Johnson Space Center**

**Flight Service Provider, Zero Gravity Corp.**

zero G
the weightless experience

**C. Marsh Cuttino, MD, FAAEM FACEP**


# Questions?

**Corey McCall**
cmccall@stanford.edu
http://transducers.stanford.edu

# Back-up Slides

# RJ Interval Results

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| | RJ Interval [ms] | | |
|---|---|---|---|
| Subject ID | Ground | Microgravity | Difference |
| 1 | 215 | 180 | 35 |
| 2 | 211 | 156 | 55 |
| 3 | 203 | 156 | 47 |
| 4 | 207 | 227 | -20 |
| 5 | 258 | 195 | 63 |
| 6 | 203 | 168 | 35 |
| 7 | 219 | 180 | 39 |
| 8 | 211 | 172 | 39 |
| 9 | 250 | 180 | 70 |
| 10 | 215 | 191 | 23 |
| | | | |
| Mean | 219.11 | 180.43 | 38.68 |
| S.Dev. | 19.10 | 20.74 | 24.80 |
| Coeff. of Var. | 8.72% | 11.49% | 64.11% |

# SNR Results

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| Subject ID | M | $SNR_r$ Estimate | | |
|---|---|---|---|---|
| | | Scale | Free-Floating | Difference Factor |
| 1 | 34 | 0.69 | 0.32 | 2.13 |
| 2 | 16 | 0.60 | 0.21 | 2.86 |
| 3 | 56 | 0.99 | 0.92 | 1.08 |
| 4 | 72 | 1.02 | 0.26 | 3.91 |
| 5 | 66 | 0.92 | 0.20 | 4.50 |
| 6 | 28 | 0.36 | 0.68 | 0.53 |
| 7 | 18 | 0.22 | 0.76 | 0.29 |
| 8 | 26 | 0.42 | 0.36 | 1.15 |
| 9 | 60 | 0.71 | 0.29 | 2.44 |
| 10 | 22 | 0.65 | 0.35 | 1.87 |
| Mean | | 0.66 | 0.44 | 2.08 |
| S.Dev. | | 0.27 | 0.25 | 1.39 |
| Coeff. of Var. | | 40.87% | 58.04% | 67.07% |

# SNR Calculation

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$$X[n] = \begin{bmatrix} x_1[n] \\ x_2[n] \\ \vdots \\ x_M[n] \end{bmatrix}, \quad n = 1, \ldots, L$$

$$SNR_r = \mathrm{A}\frac{r}{1-r} + B$$

$$r = \frac{\frac{1}{L}\sum_{n=1}^{L}(x_j[n] - \overline{x_j})(x_k[n] - \overline{x_k})}{\sqrt{\frac{1}{L}\sum_{n=1}^{L}(x_j[n] - \overline{x_j})^2 \frac{1}{L}\sum_{n=1}^{L}(x_k[n] - \overline{x_k})^2}}$$

$$A = \exp\left(\frac{-2}{L-3}\right) \qquad \mathrm{B} = -\frac{1}{2}\left(1 - \exp\left(\frac{-2}{L-3}\right)\right)$$