



Noninvasive Diagnosis and Real-time Evaluation of the Effects of Hyperbaric Dive Environments on the Autonomic Nervous System Utilizing Principal Dynamic Mode Analysis

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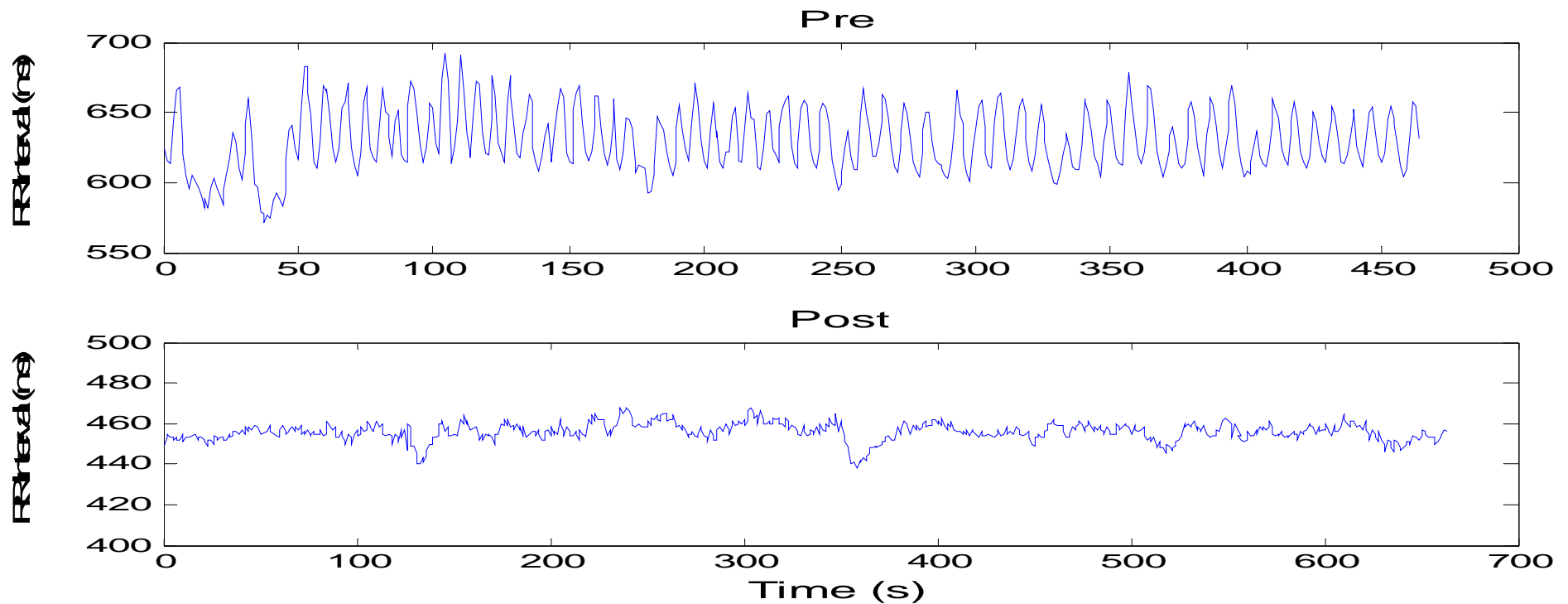
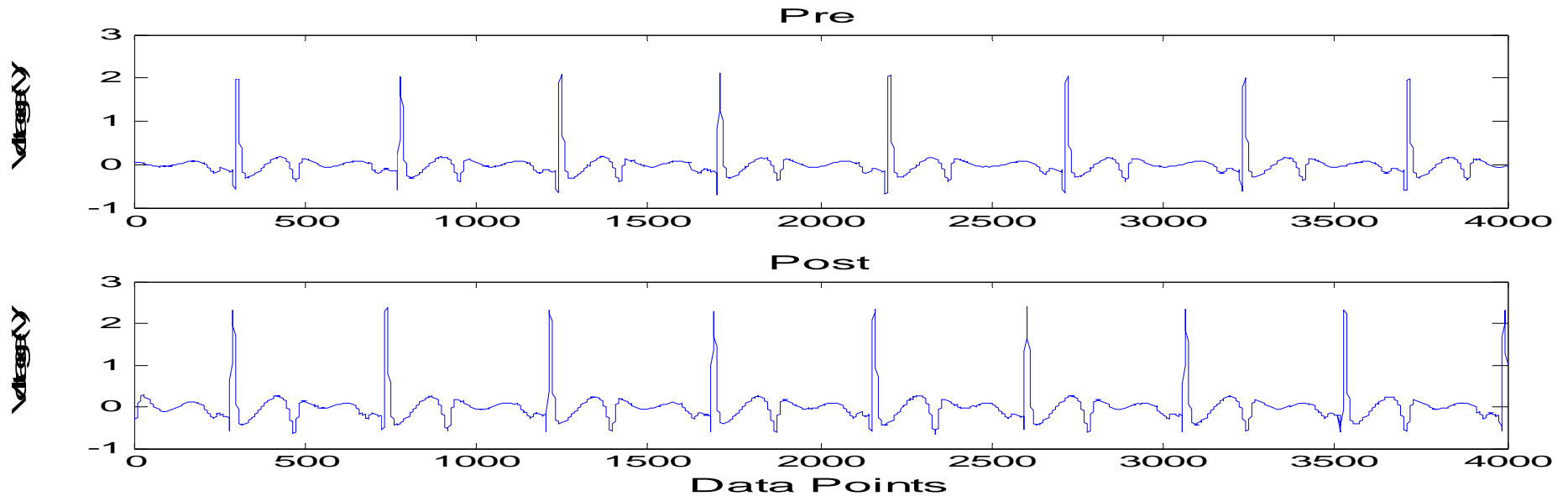
³NMRC, Bethesda, MD



Outline

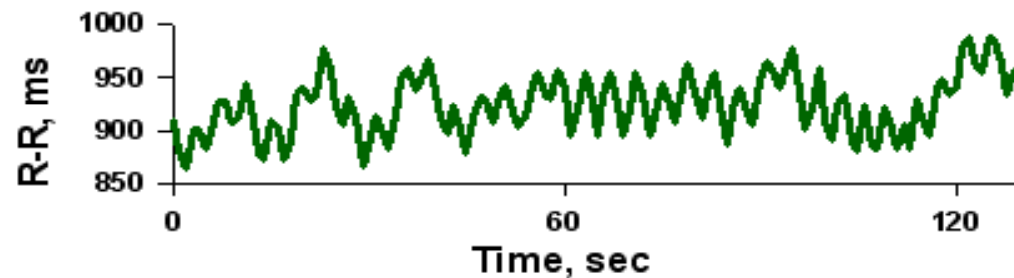
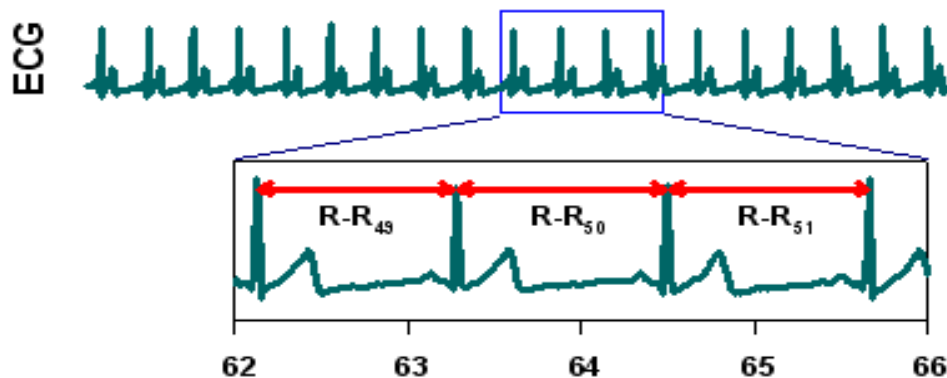
- 1): To find a marker for determining threshold levels as indicators of stress from incipient hyperbaric stress or DCS conditions in a swine model**
- 2): Wearable & mobile pulse oximeter sensor development for data collection and analyses**

Swine's ECG may be normal, but HR variability is significantly reduced in swine with neurological DCS



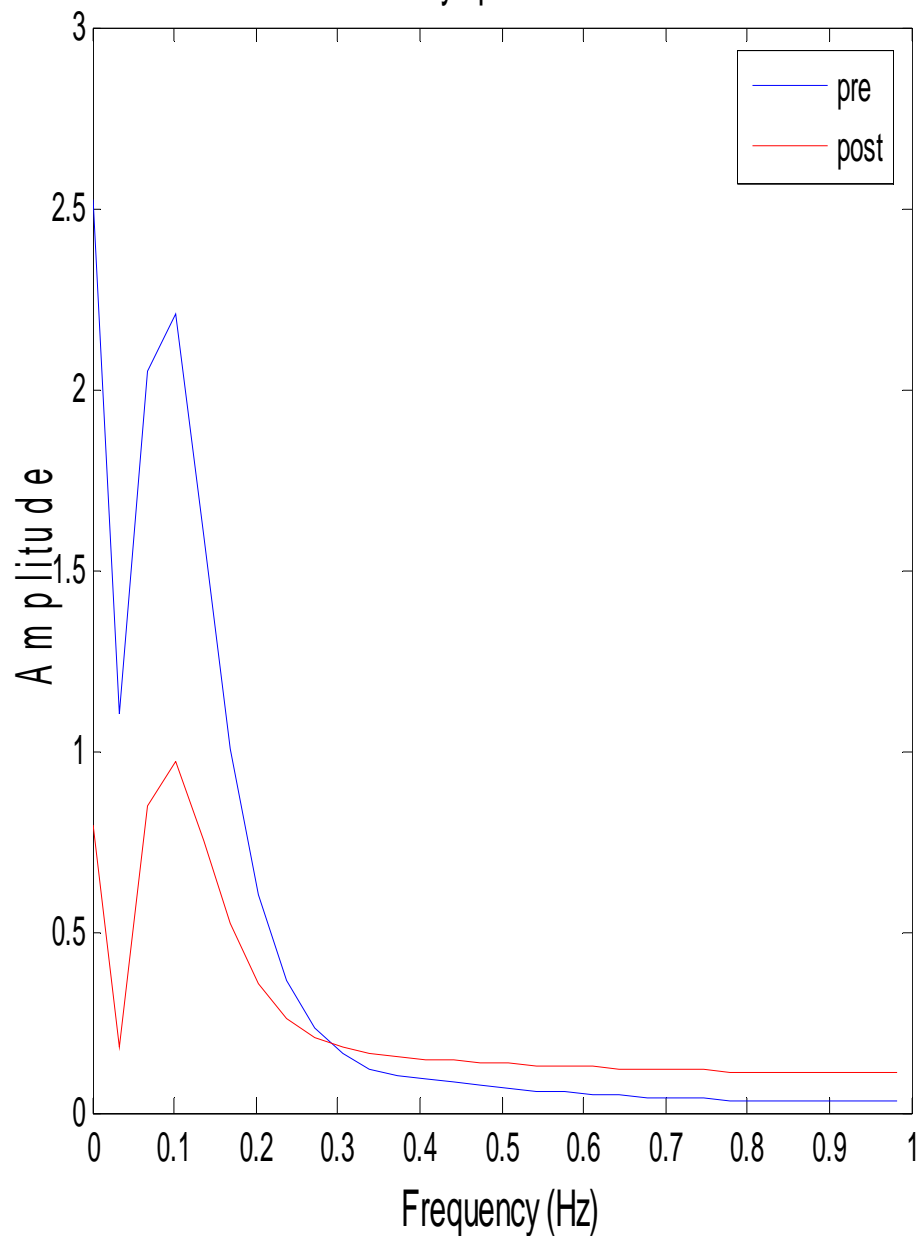
Experimental Design

- 13 male, Yorkshire swine were used
- Telemetry ECG data were collected for 10-15 minutes during **pre- and post-dive**
- Experiment conditions:
 - Dive chamber pressurized to 200 fsw at 30 ft/min for duration of 24-31 minutes
 - Decompression rate of 60 fsw/min
- Collect ECG → R-R interval → HRV

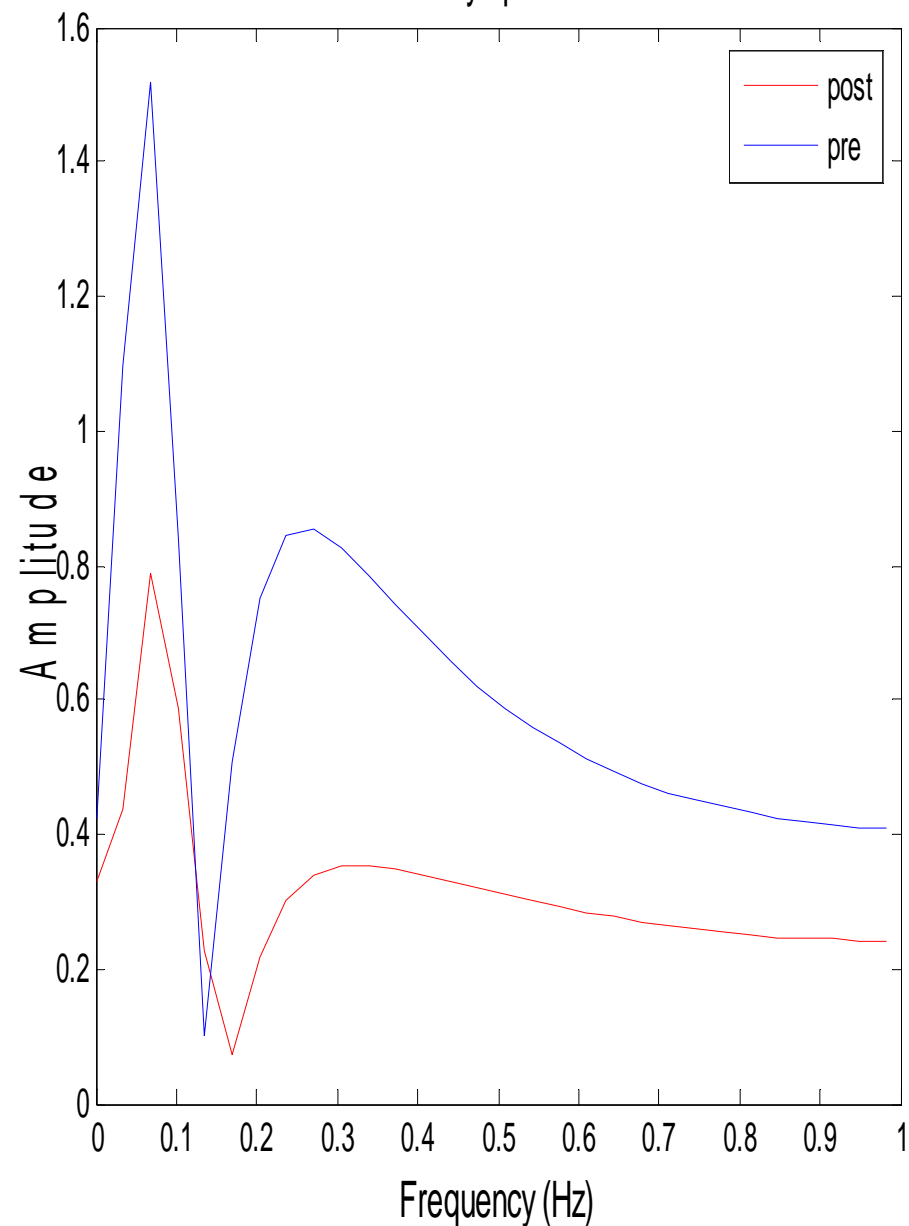


PDM Swine Results

Sympathetic

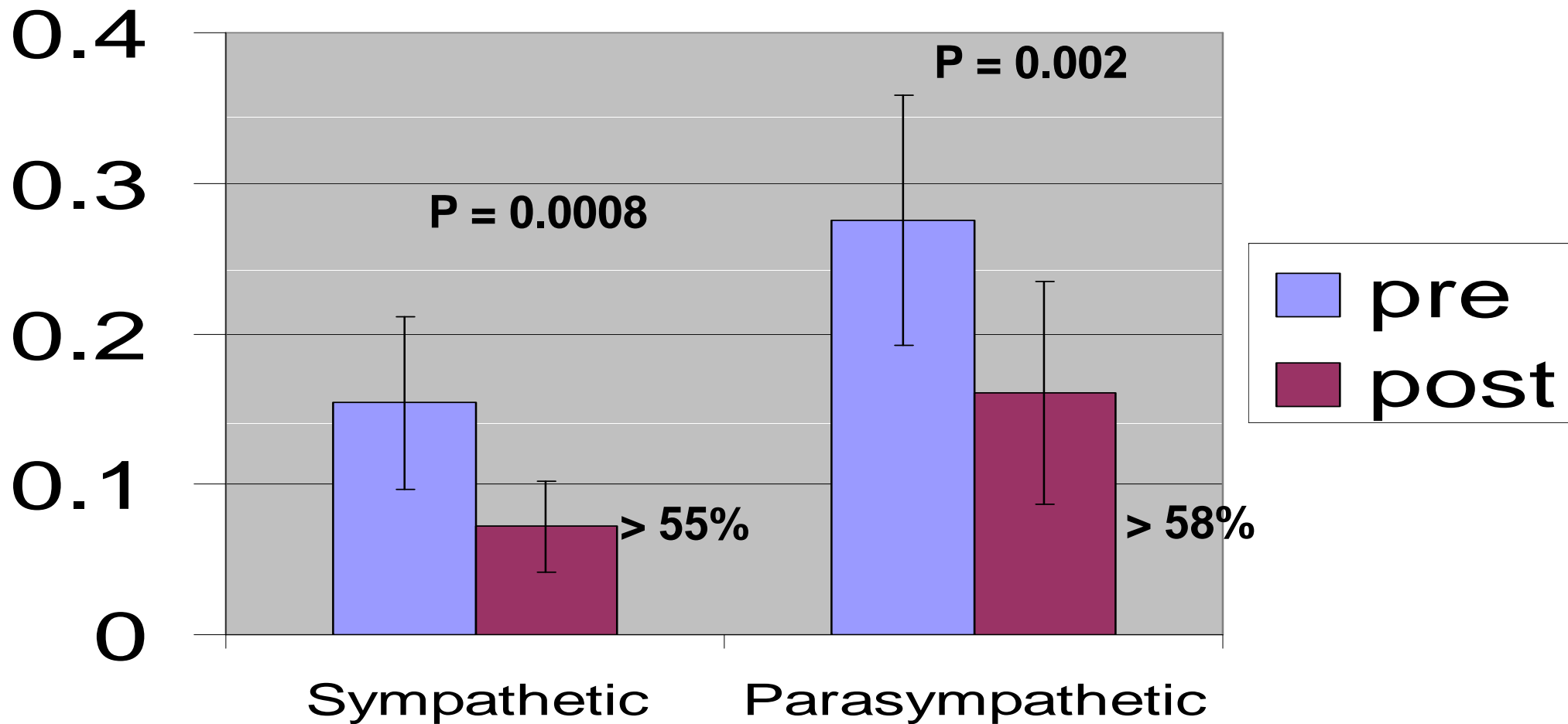


Parasympathetic



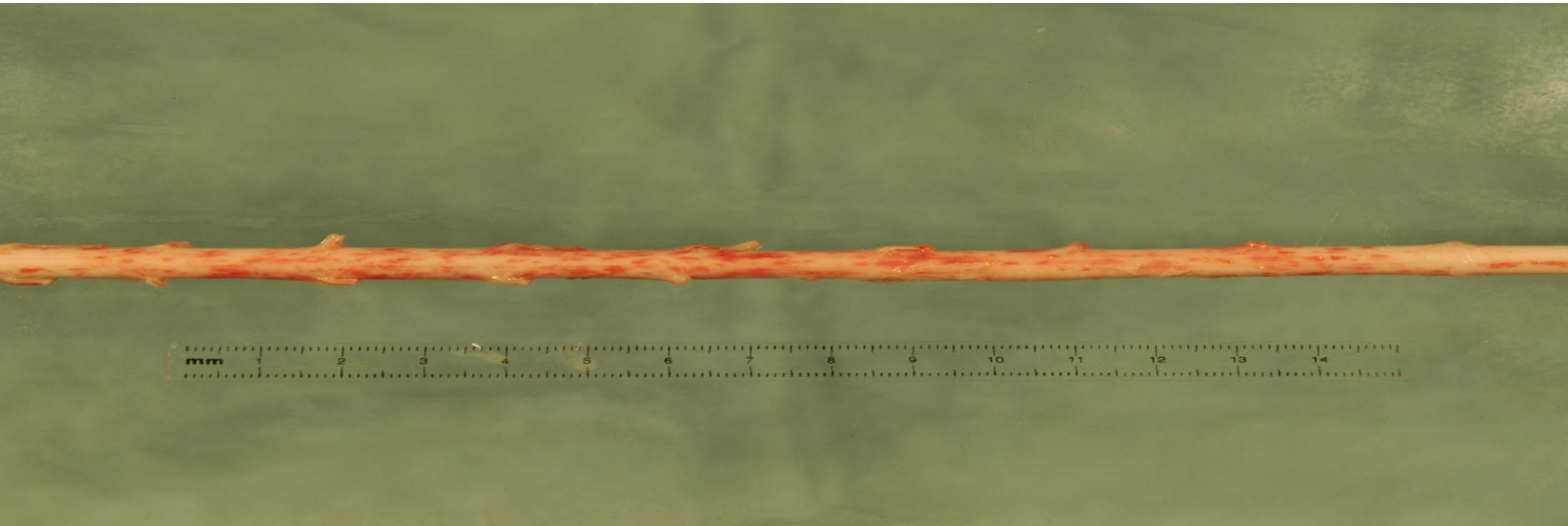
PDM Swine Results

N = 13 swine



•variance of HR, RMSSD, ApEn all show non-significant decrease in the post DCS when compared to pre DCS Bai et al., JAP, 2009

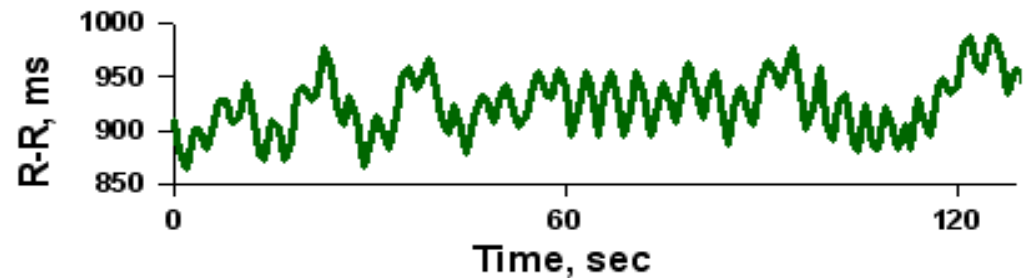
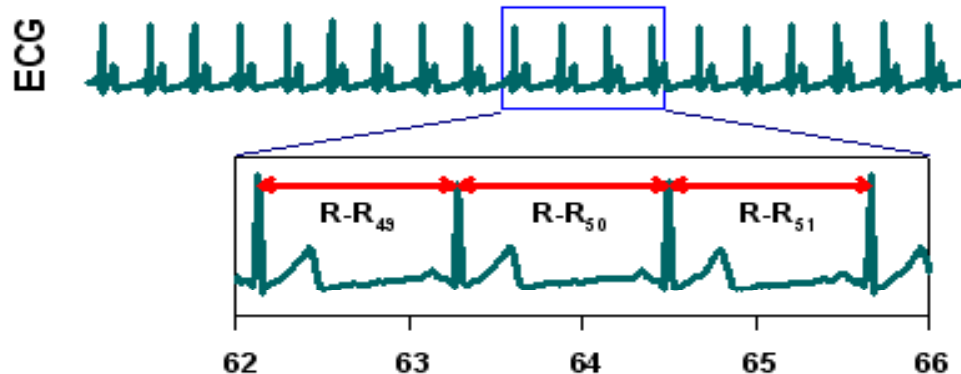
PDM Swine Results



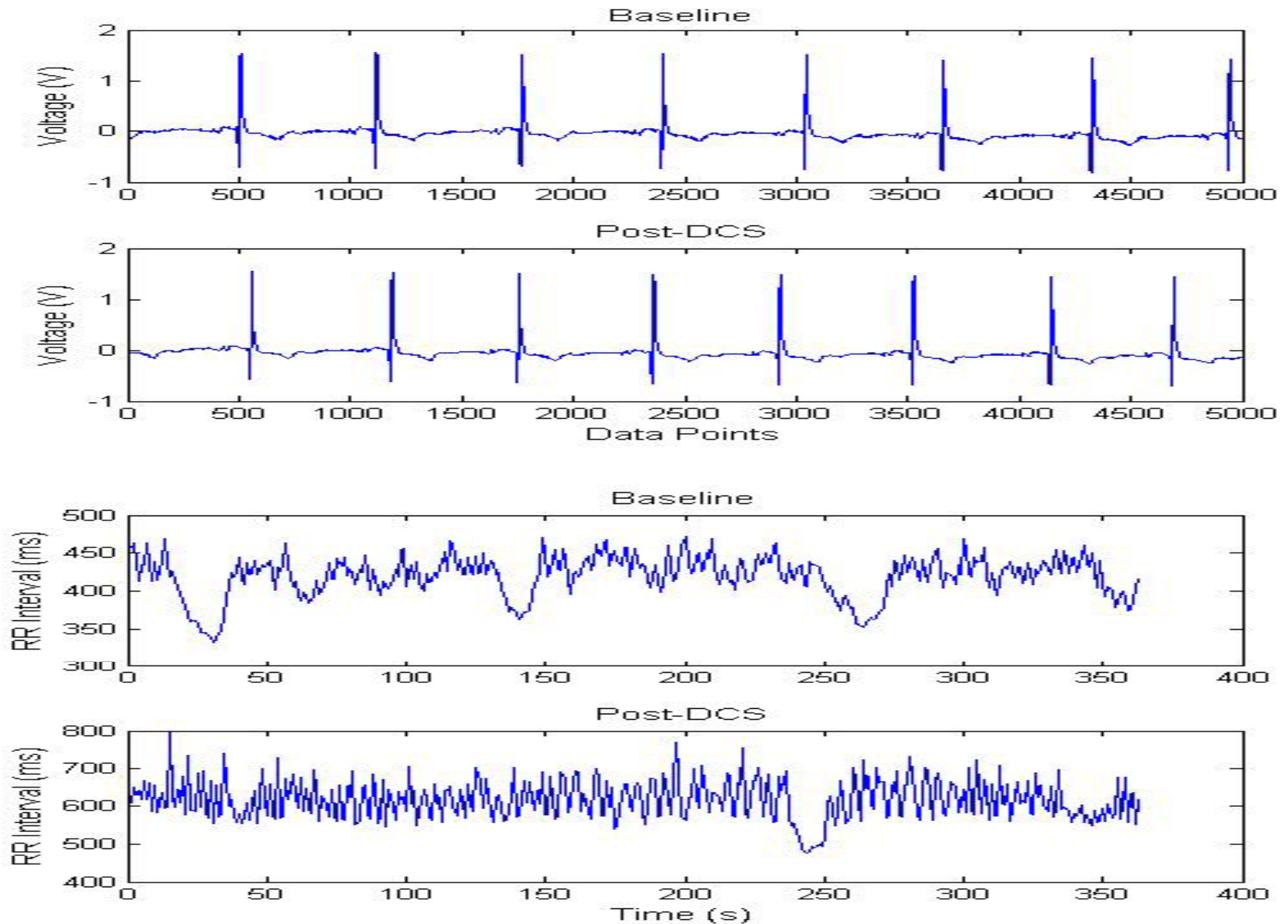
- Spinal cord injury consisted of hemorrhage and axonal degeneration
 - Spinal cord injury was confirmed by H&E staining

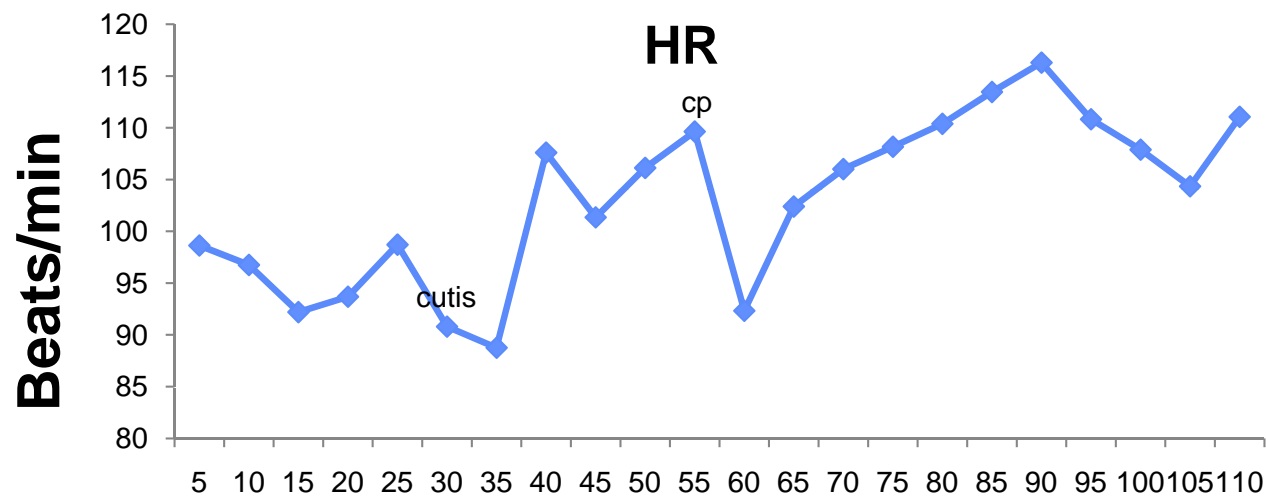
Experimental Design

- 9 male, Yorkshire swine were used
- **Continuous** telemetry ECG data were collected during entire duration
- Experiment conditions:
 - saturation dive at 60 fsw for ~15 hours followed by a rapid decompression to the surface in 2-3 minutes
- Collect ECG → R-R interval → HRV

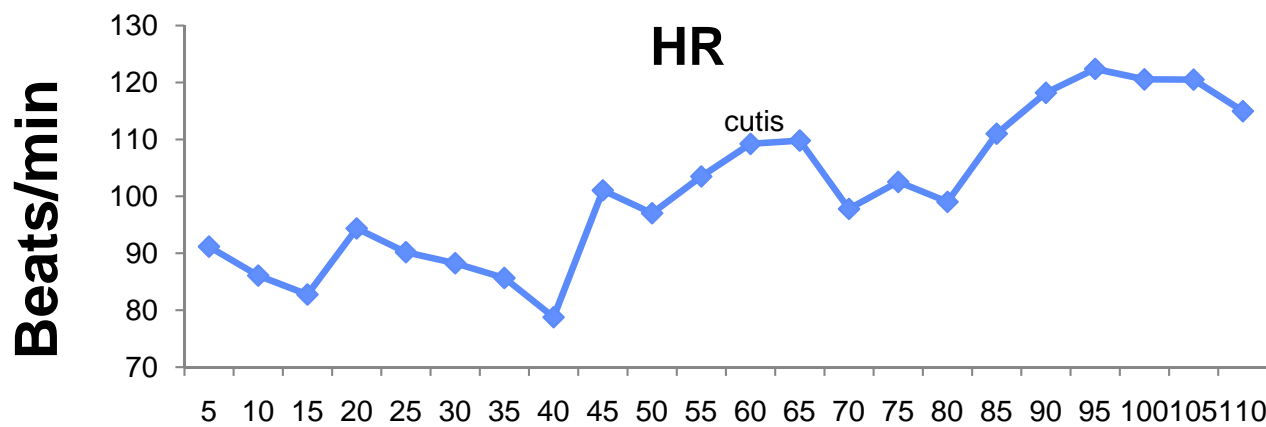


Swine's ECG may be normal, but HR variability is significantly increased in swine with cardiopulmonary & cutis DCS

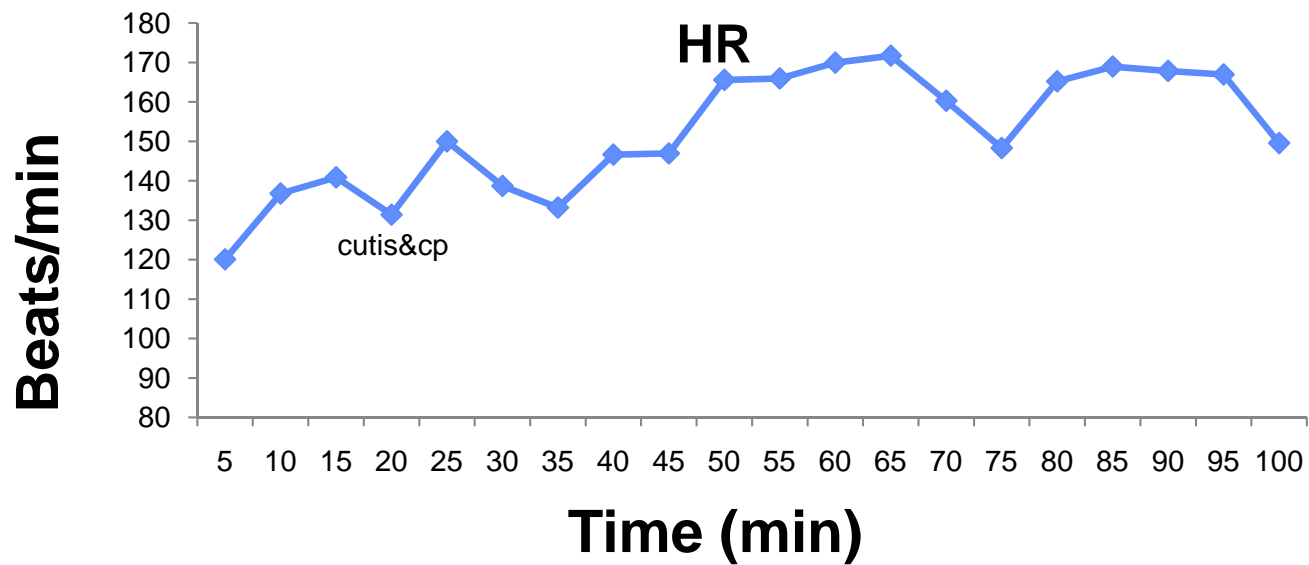




Swine #1

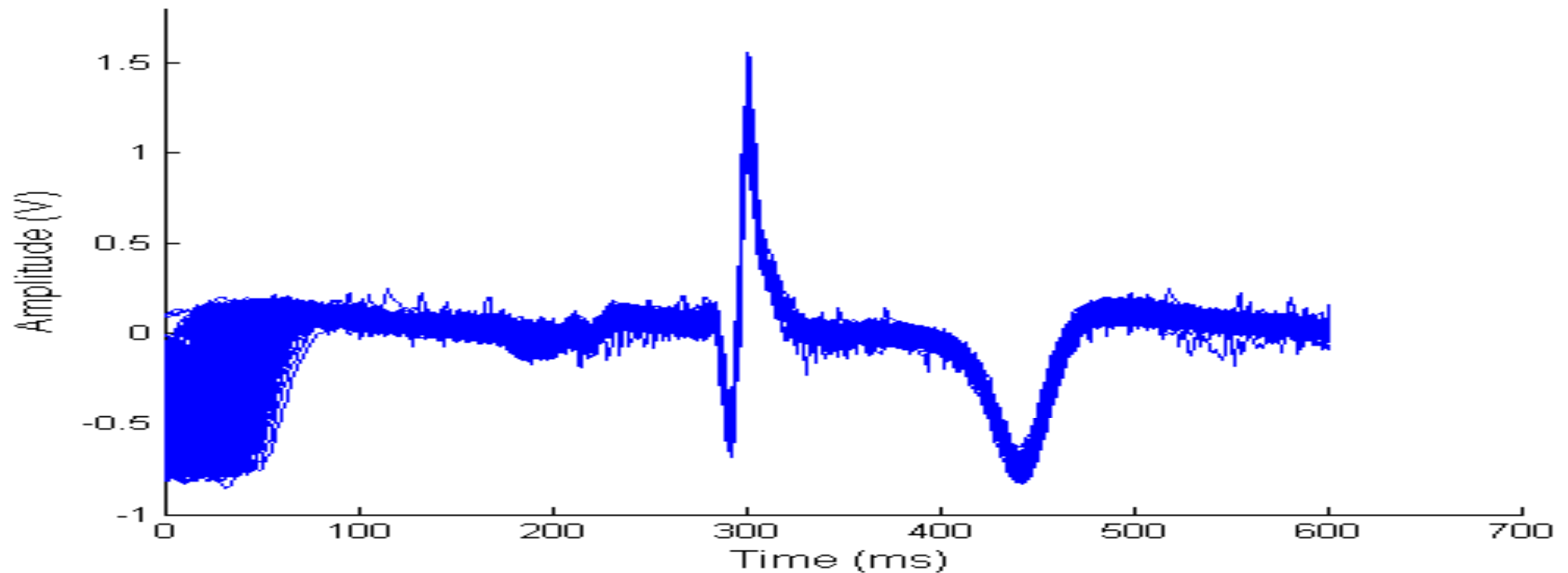
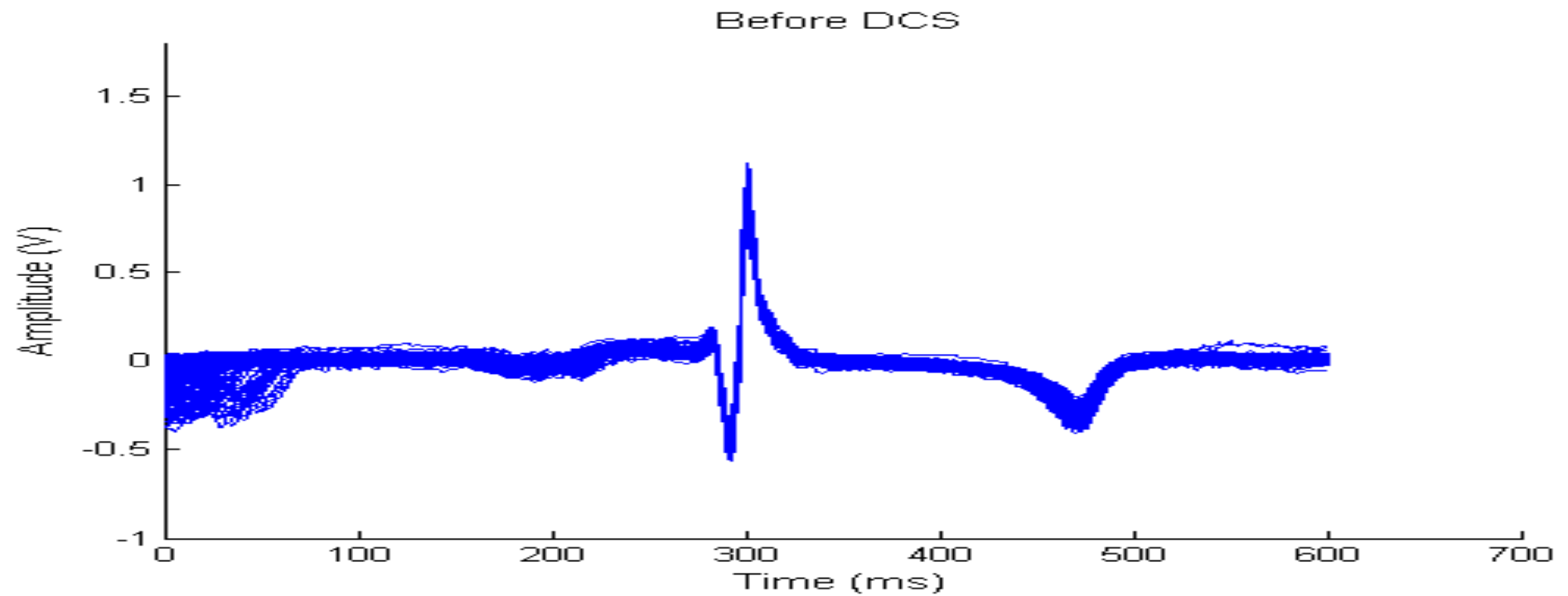


Swine #2



Swine #3

ECG Morphology difference between Pre- and Post-DCS



Results: Heart rate and ECG morphologies

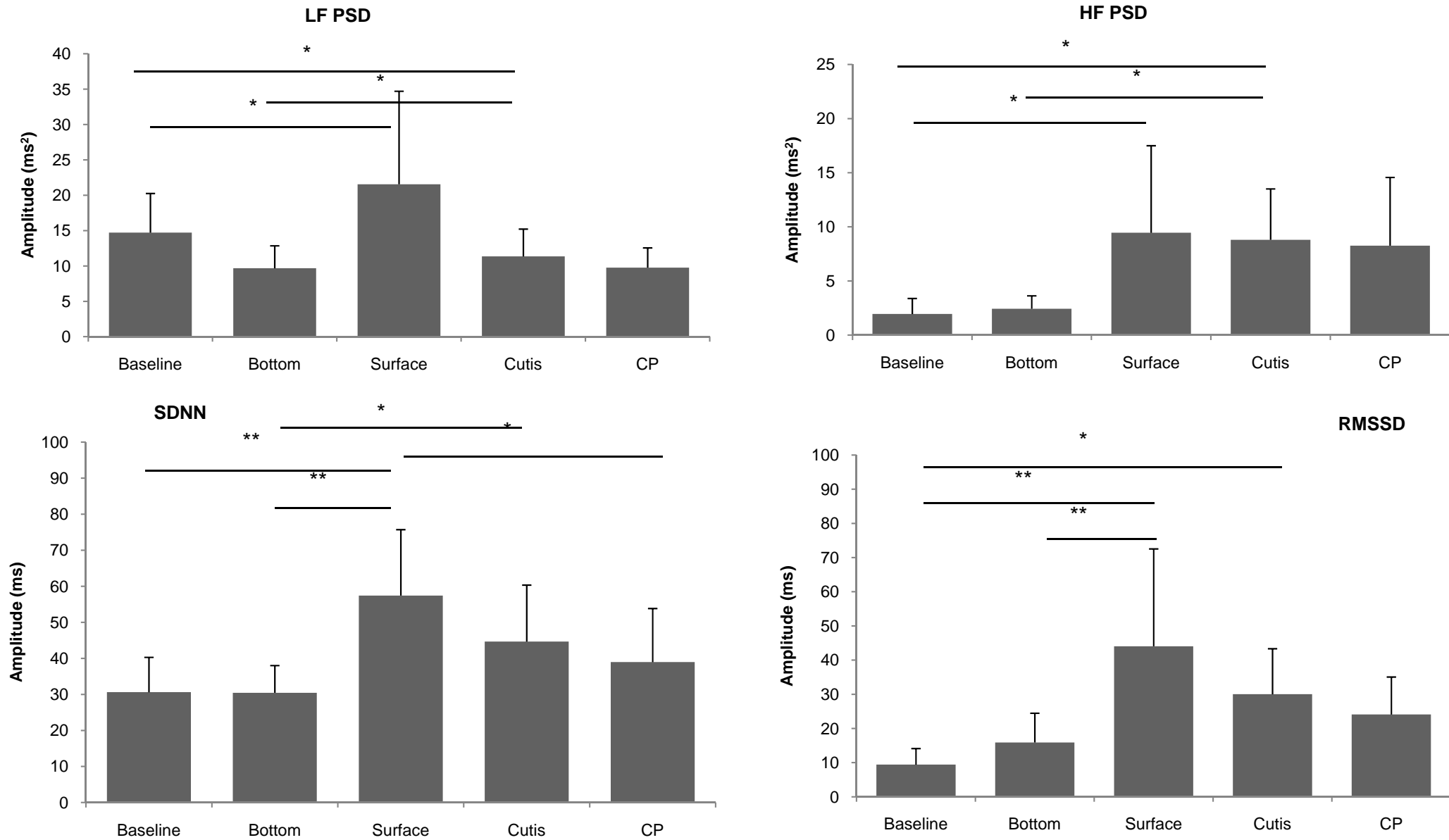
	Heart Rate (beats/min)	QRS duration (s)	ST elevation (V)	T wave Amplitude (V)	QT interval (s)	QT c
#Baseline(n=7)	127.33 ± 11.24	0.0638 ± 0.0013	0.00625 ± 0.0070	-0.293 ± 0.091	0.239 ± 0.013	0.346 ± 0.017
Bottom (n=9)	110.34 ± 10.12*	0.0635 ± 0.0016	0.0132 ± 0.0068	-0.275 ± 0.150	0.264 ± 0.023	0.356 ± 0.020
Surface (n=9)	95.29 ± 14.62*	0.0640 ± 0.0017	0.00856 ± 0.0078	-0.245 ± 0.114	0.273 ± 0.021*	0.342 ± 0.020
Cutis (n=9)	109.55 ± 21.35*	0.0640 ± 0.0018	0.00215 ± 0.0152	-0.458 ± 0.193†	0.254 ± 0.024	0.338 ± 0.026
CP (n=6)	120.07 ± 20.37†	0.0640 ± 0.0020	0.00952 ± 0.0367	-0.477 ± 0.259	0.247 ± 0.028	0.343 ± 0.030

* p < 0.05 compared to baseline

† p < 0.05 compared to surface

n = 7 because there were no baseline measurements for 2 swine.

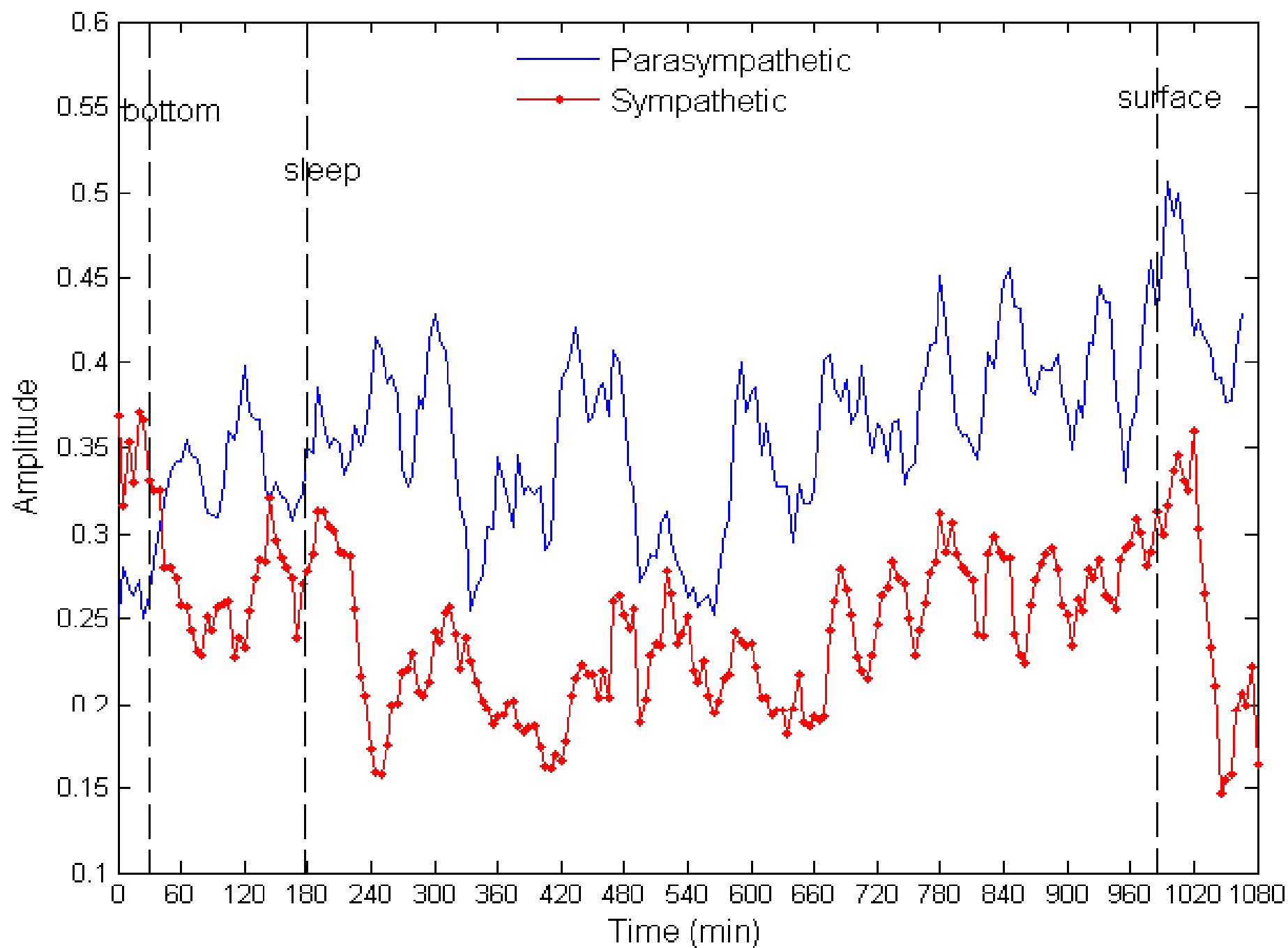
Summary of Results



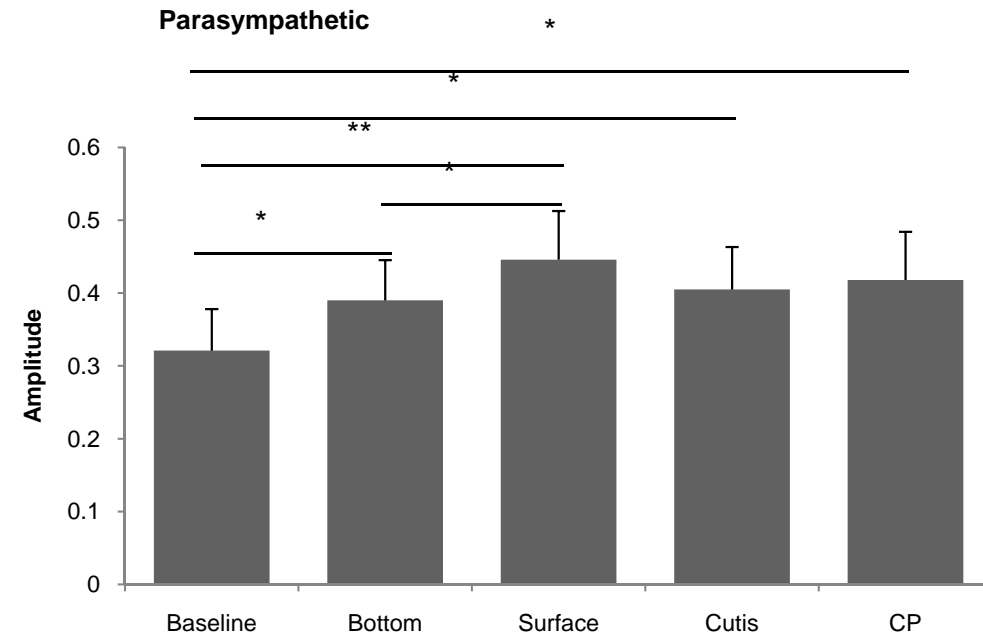
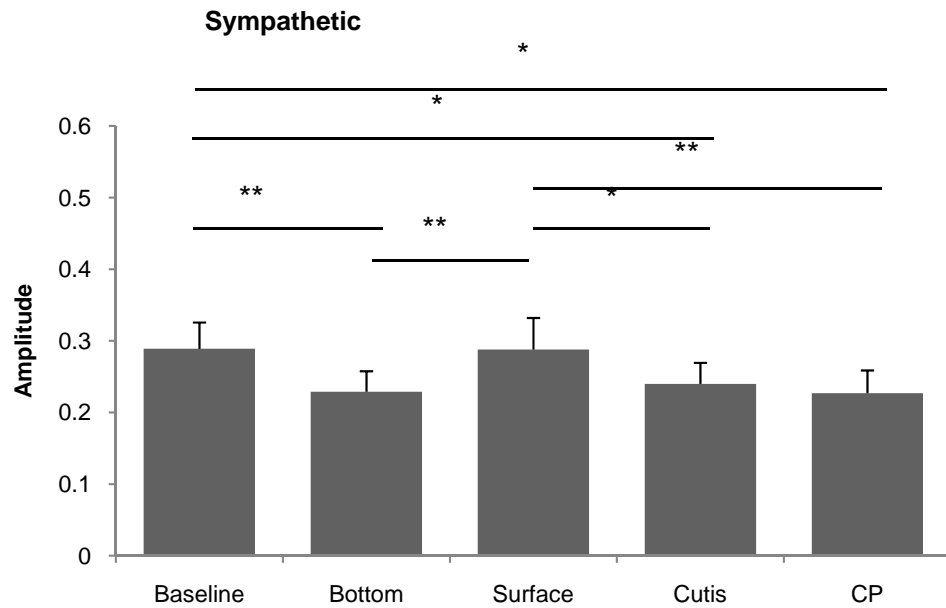
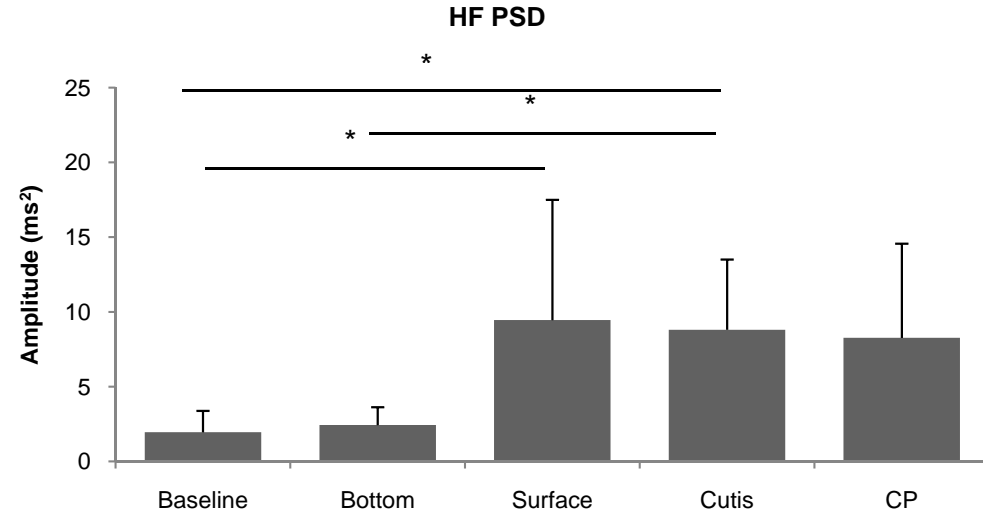
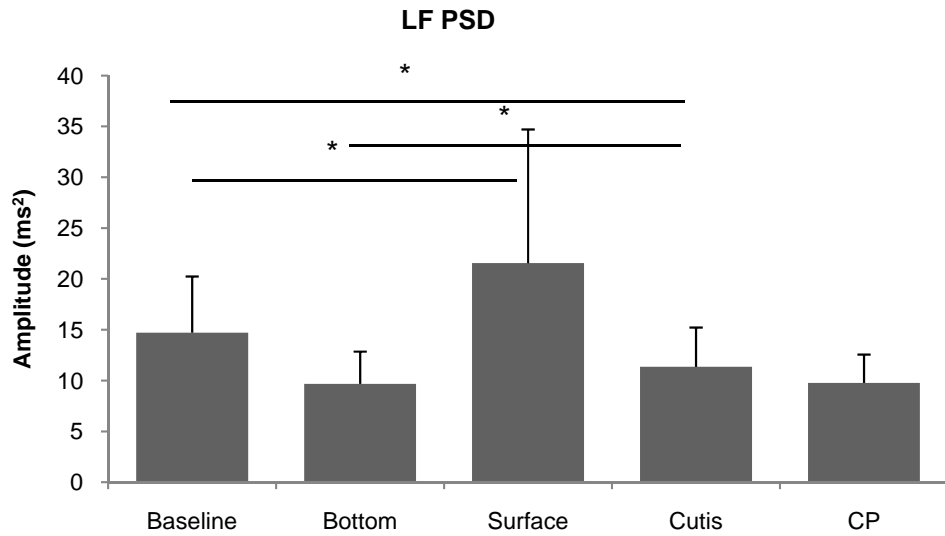
* $p < 0.05$

** $p < 0.01$

Representative Parasympathetic and Sympathetic Dynamics



Summary of Results



* $p < 0.05$

** $p < 0.01$

Time (mins) of event onsets after surfacing

Event	Number of subjects	Minutes after surfacing
Cutis	9	37.78 ± 23.83
CP	6	41.67 ± 27.01
RMSSD	9	$10.00 \pm 15.00^{*\dagger}$
HF	9	$12.22 \pm 15.63^{*\dagger}$
Parasympathetic	9	$9.44 \pm 6.35^{*\dagger}$

For cutis and CP, the table shows the average onset time of these two symptoms; n = 9 for all events, except CP (n = 6). For RMSSD, HF and the parasympathetic dynamics, the table lists the average time when the post-dive values of these parameters first became higher than their mean values at bottom.

* p<0.05 when compared to cutis

†p<0.05 when compared to CP

Conclusion and Discussion

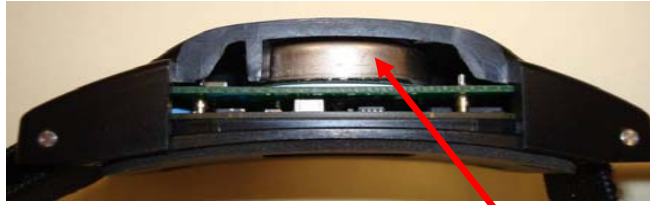
- **Early detection of type I (cutis) and II (cardiopulmonary) DCS via our method may be possible**
 - **~20-30 minutes early detection prior to trained human observers**
 - **Differentiation between neurological and cardiopulmonary DCS possible**
- **New experiments are planned to examine PDM's robustness:**
 - **Less severe DCS**
 - **40% type II DCS & 90% type I DCS**
 - **15% type II DCS & 50% type I DCS**
 - **No type II DCS & 20% type I DCS**
- **Treatment of DCS --→ oxygen prebreathing -→ oxygen toxicity & seizure: (due to increase of sympathetic and/or parasympathetic?)**

Instrumentation & Demo

Wearable Wireless Physiological (pulse ox) Sensor



Head Band



Optical Module

Disposable battery



- Flexible Configuration
- Rechargeable Battery

- SpO_2
- HR
- HRV –
sympathetic/parasympathetic
- Arrhythmia detection
- Respiration rate
- Perfusion Index
- Posture
- Activity
- Skin temperature
- Motion artifact detection
- Carboxyhemoglobin ($SpCO$)
- Core body temperature*
 - Hydration/fluid volume responsiveness

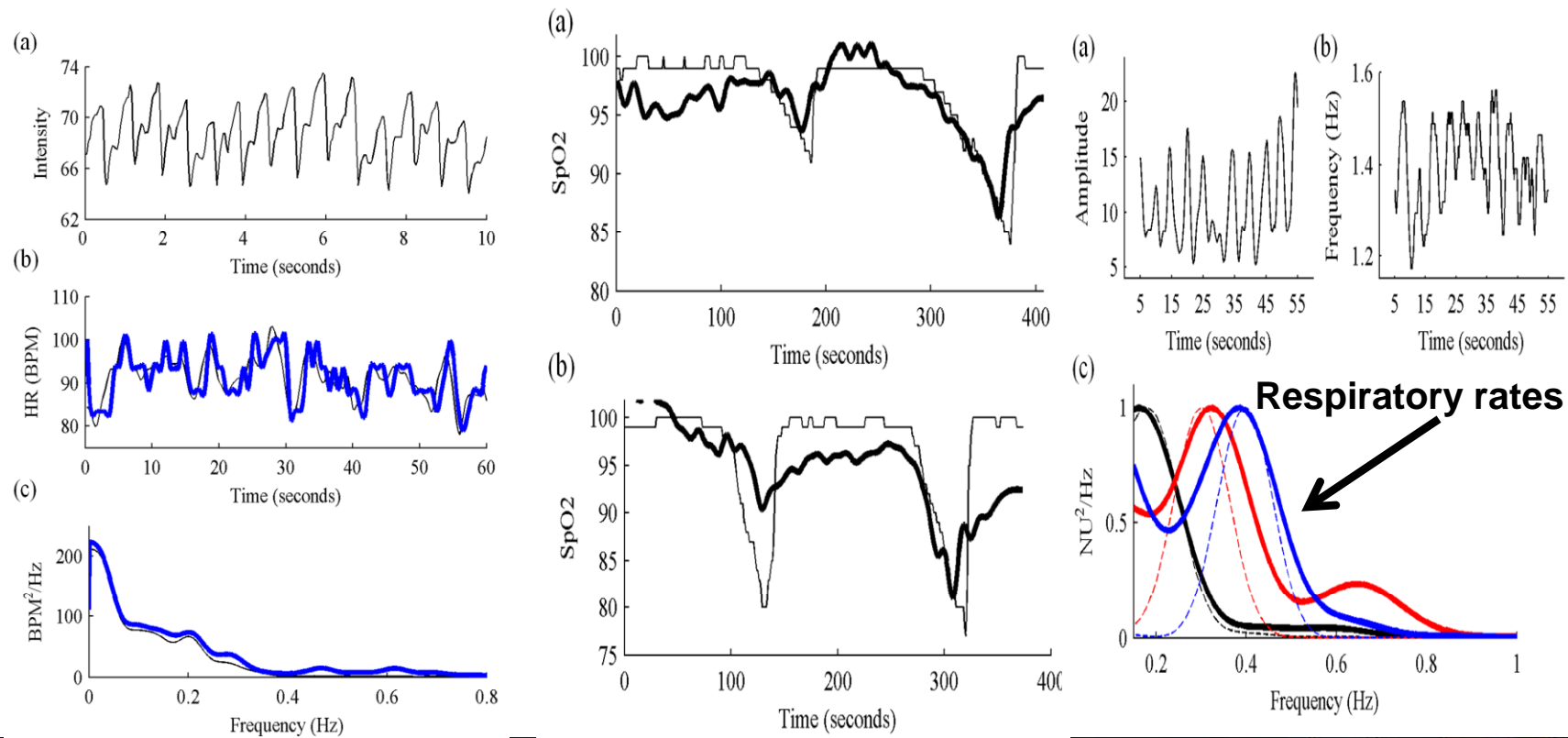
Streaming Measurements:



USB-Based Receiver



Vital Sign Monitoring via Motorola Droid Cell-phone



Acknowledgements

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