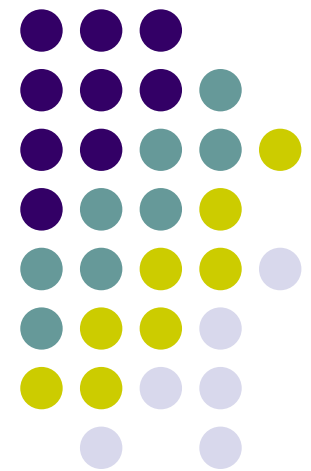


Wavelet Signal Processing and Machine Learning for Prediction of Hemorrhagic Shock

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VCU

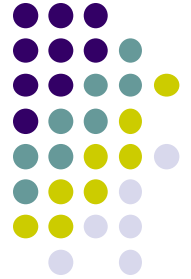
Virginia Commonwealth University



Traditional HRV Analysis

- Power Spectral Density
 - Strength of variations in correlation function of a signal in frequency (Fourier) domain
- Fractal Dimension
 - Self similarity of signal at different scales
 - Measures complexity of the signal and detects if the signal is becoming “too simple” to be healthy
- Our approach: Discrete Wavelet Transform
 - Ideal for non-stationary signals

Study 1: Analysis and Comparison of Information in HRV for LBNP vs. Exercise



Traditional HRV Methods Vs. DWT based Method

ECG Data Provided from LBNP and Exercise
Subjects Studied by USAISR: Convertino,
Ryan, Cooke, and Rickards.

Assessment of Discrimination Capability of Traditional HRV and Wavelet Methods



- Objective: Identify which method can distinguish between LBNP and Exercise
- 13 Subjects undergo both LBNP and Exercise tests
 - Data are used for comparison of the two methods
 - Traditional HRV methods apply PSD (FFT) based techniques as well as Fractal dimension (FD)
 - Discrete Wavelet Transformation with Daubechies 4 (db4)



LBNP & Exercise Datasets

LBNP		Exercise	
Collapse Stage	# of Subject	Collapse Stage	# of Subject
4	5	4	2
5	1	5	11
6	5		
7	2		
Total	13		13

ANOVA Test of Traditional HRV Methods: LBNP vs. Exercise



Stage	HF (125Hz)	LF (125Hz)	VLF (125Hz)	LF_nm (125Hz)	HF_nm (125Hz)	LF/HF (125Hz)	HF/LF (125Hz)	Higuchi (125Hz)
Baseline	0.8513 (0.5270)	0.3244 (0.2469)	0.4549 (0.1035)	0.5159 (0.06)	0.5507 (0.1138)	0.9764 (0.2743)	0.1938 (0.1298)	0.0636 (0.0873)
Stage 1	0.7181 (0.7014)	0.6786 (0.4693)	0.1165 (0.3406)	0.6577 (0.4908)	0.6653 (0.8951)	0.6775 (0.2862)	0.9029 (0.8226)	0.1427 (0.3705)
Stage 2	0.9588 (0.9837)	0.9472 (0.7155)	0.6271 (0.7378)	0.6767 (0.6007)	0.6530 (0.7947)	0.4978 (0.3529)	0.4529 (0.3865)	0.0885 (0.1873)
Stage 3	0.5692 (0.4598)	0.4065 (0.7297)	0.2091 (0.0871)	0.7655 (0.8661)	0.4833 (0.3475)	0.9625 (0.9110)	0.8235 (0.8977)	0.0544 (0.0606)
Stage 4	0.9394 (0.7872)	0.0306 (0.0477)	0.1055 (0.190)	0.0518 (0.6304)	0.1682 (0.8397)	0.2272 (0.6078)	0.1913 (0.4327)	0.0037 (0.0073)

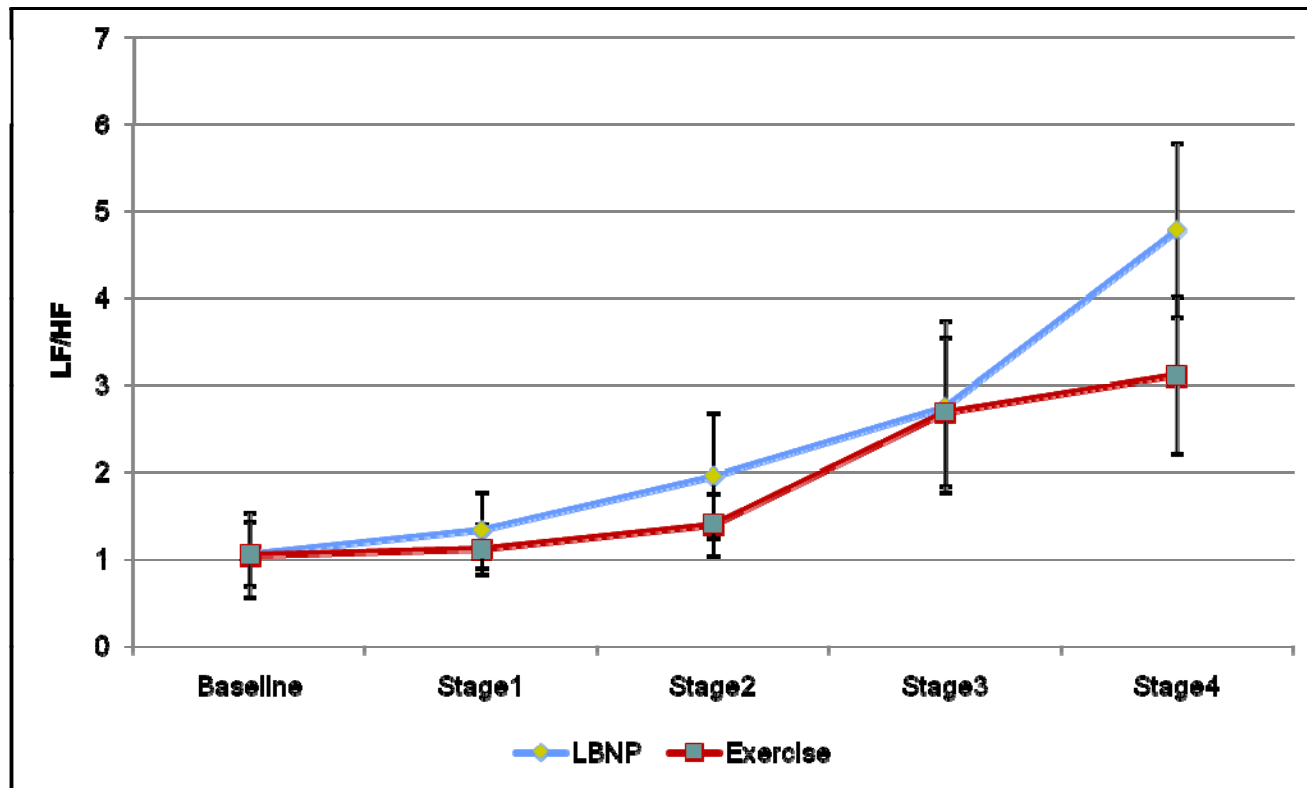


ANOVA Test of Wavelet Method

Stage	Wavelet Level 1 (125Hz)	SD-Squares Level 1 (125Hz)	Entropy of Wavelet Coef.
Baseline	0.4866 (0.6892)	0.4684 (0.5787)	0.7768 (0.7584)
Stage 1	0.0538 (0.0794)	0.0126 (0.0201)	0.0518 (0.1396)
Stage2	0.0174 (0.0241)	0.0005 (0.0020)	0.0044 (0.0347)
Stage 3	0.0112 (0.0248)	0.0117 (0.0202)	<0.0001 (0.0005)
Stage 4	0.0378 (0.0407)	0.0243 (0.0406)	<0.0001 (<.0001)

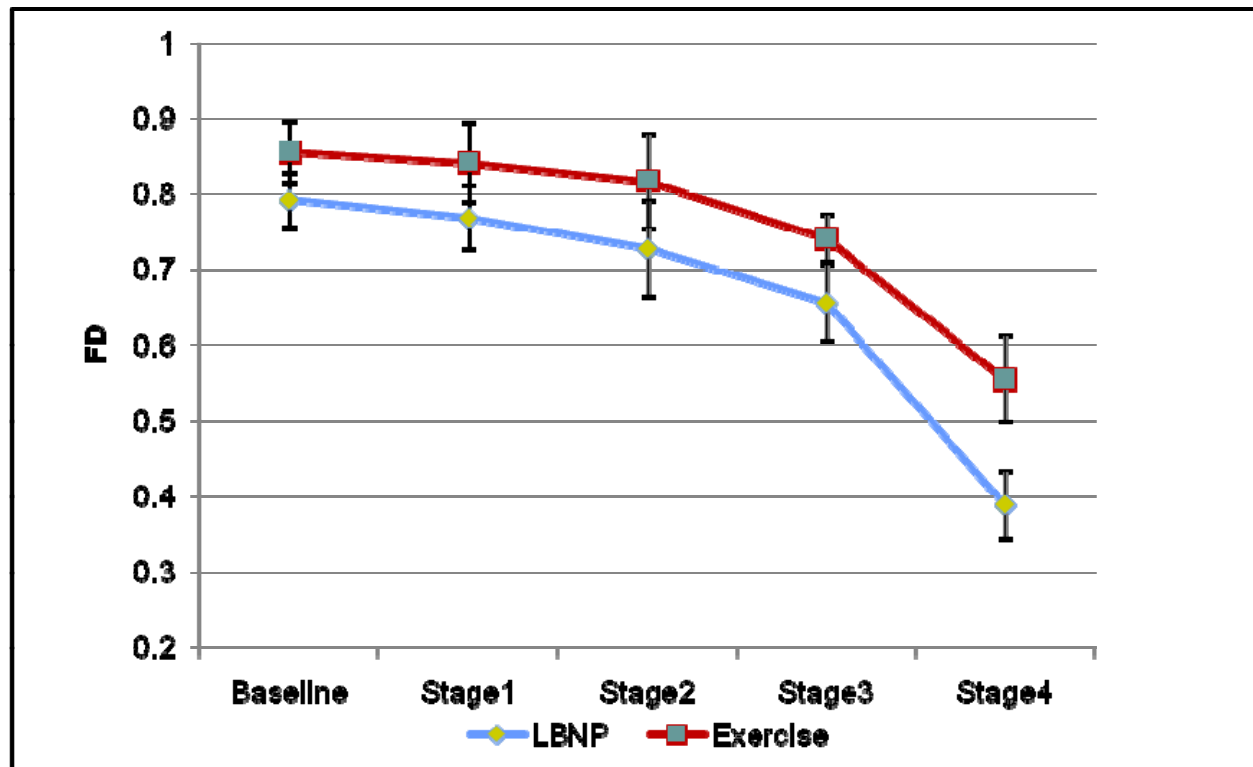


PSD - LBNP Vs. Exercise



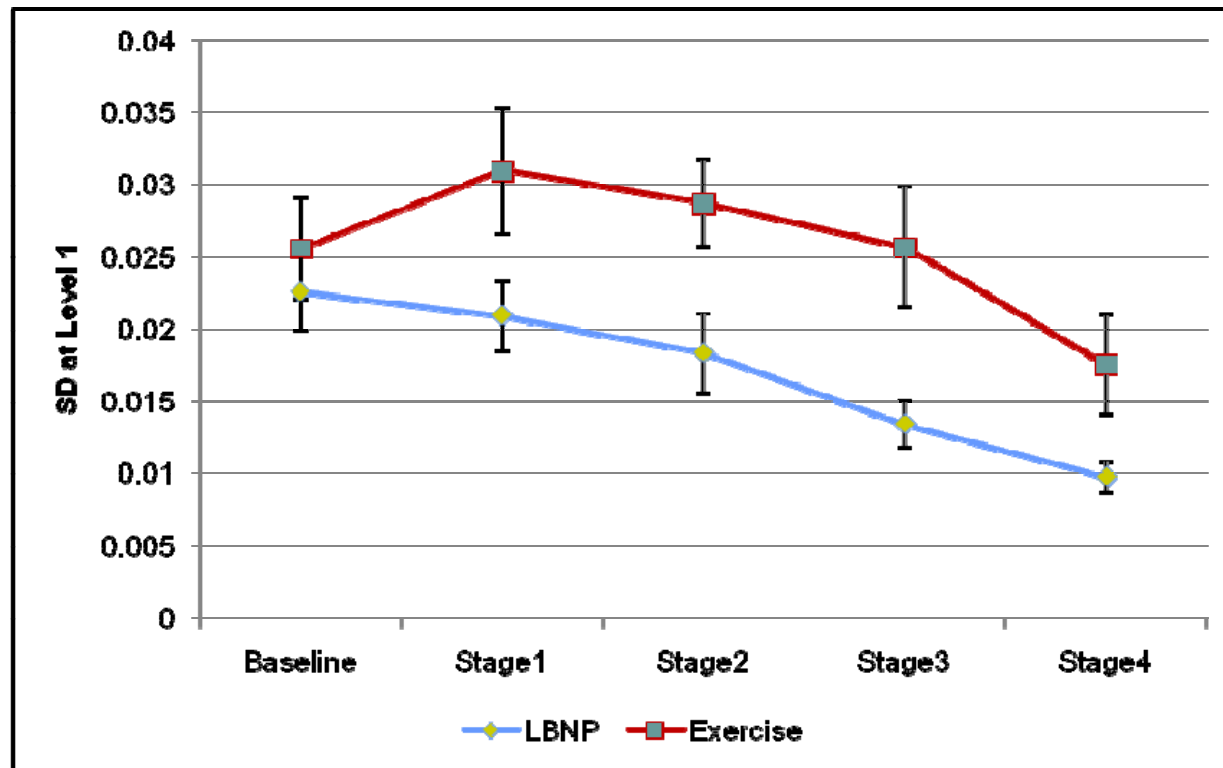


FD - LBNP Vs. Exercise

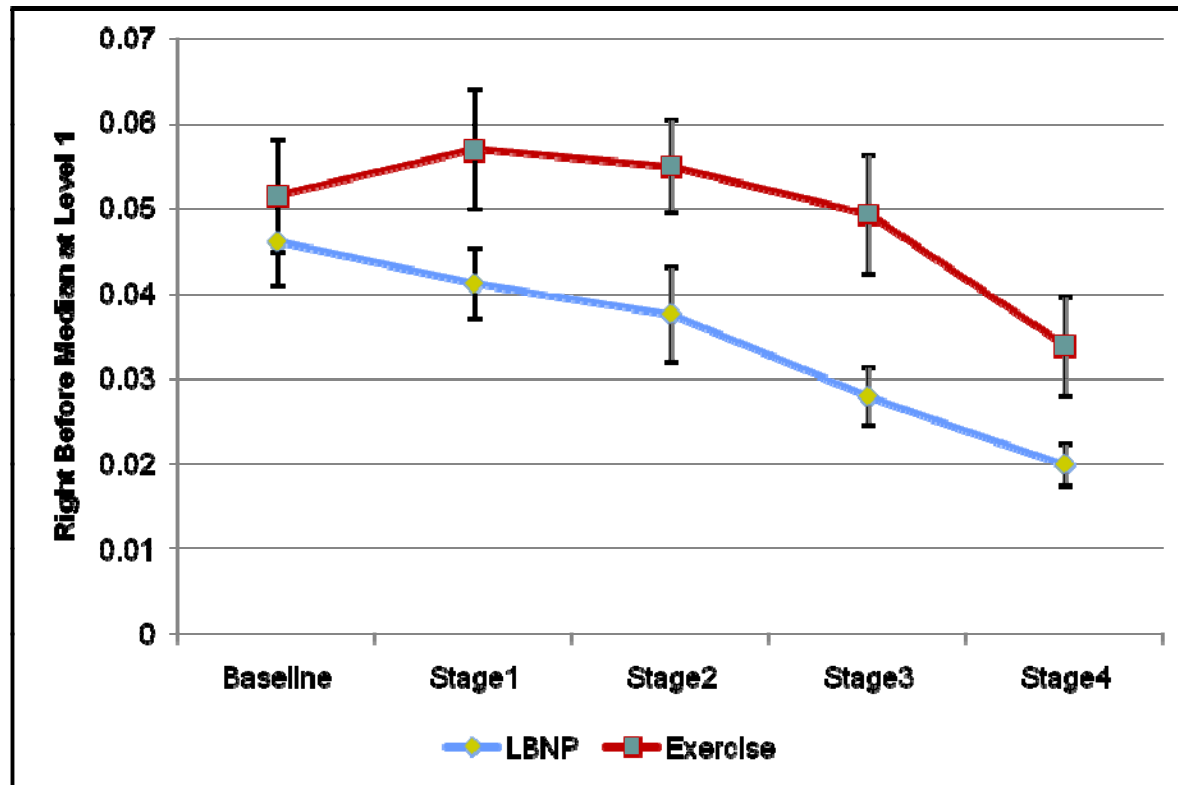
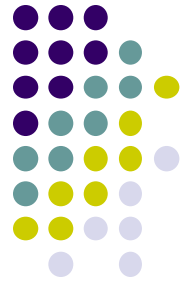




DWT- LBNP vs. Exercise



DWT- LBNP vs. Exercise (Cont'd)



Classification Labels for Three Classes



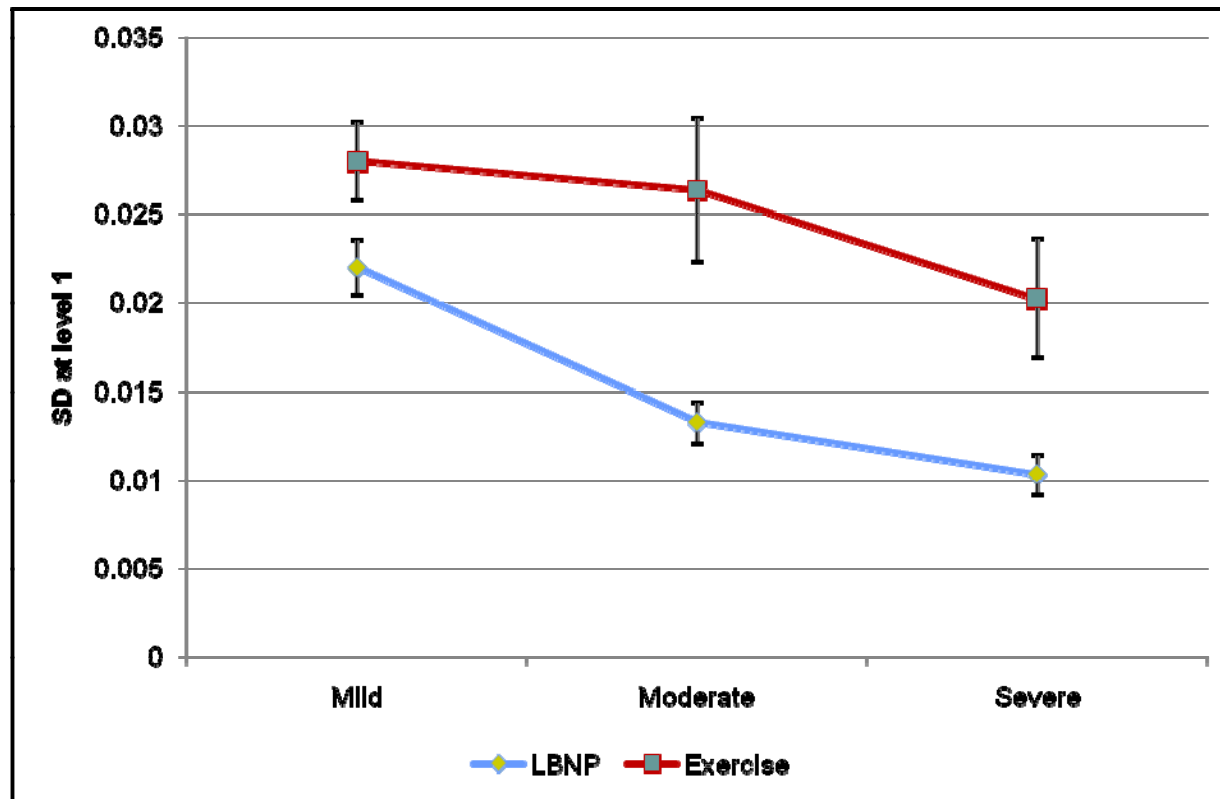
Collapse Stage	Mild	Moderate	Severe
7	Baseline, Stage 1,2, and 3	Stage 4 and 5	Stage 6 and 7
6	Baseline, Stage 1 and 2	Stage 3 and 4	Stage 5 and 6
5	Baseline, Stage 1 and 2	Stage3	Stage 4 and 5
4	Baseline and Stage 1	Stage2	Stage 3 and 4

Classification Labels for Two Classes

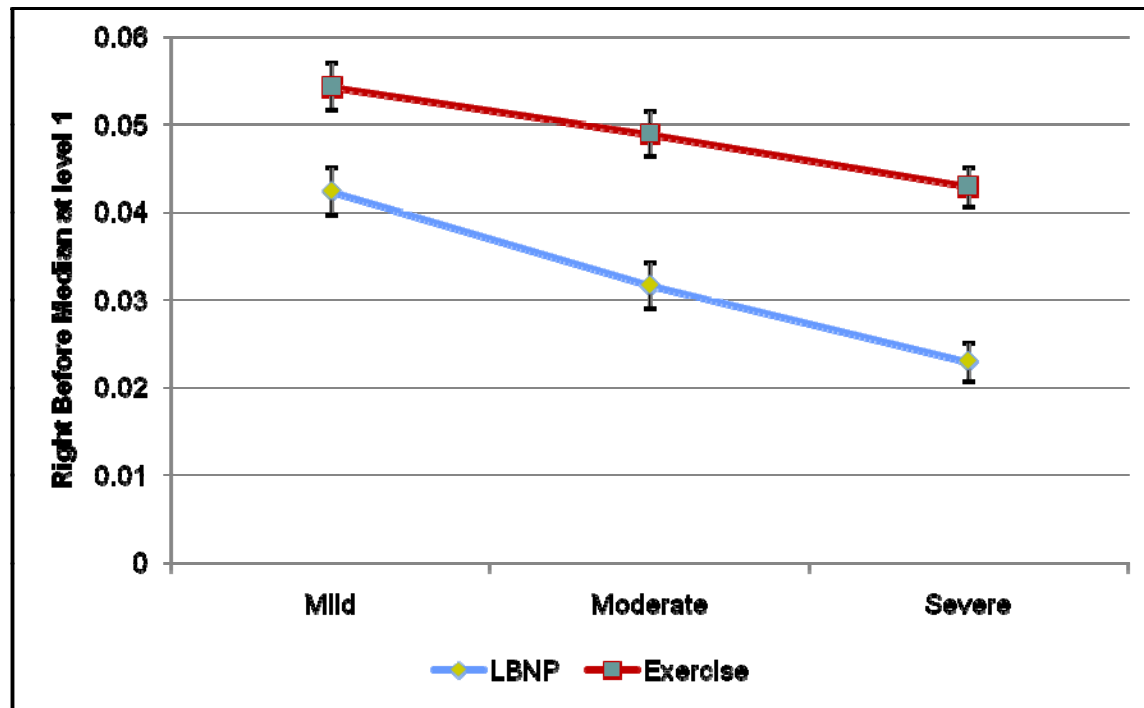


Collapse Stage	Non-Severe	Severe
7	Baseline, Stage 1,2, and 3	Stage 4, 5,6, and 7
6	Baseline, Stage 1,2, and 3	Stage 4 5, and 6
5	Baseline, Stage 1 and 2	Stage3, 4, and 5
4	Baseline, Stage 1, and 2	Stage 3 and 4

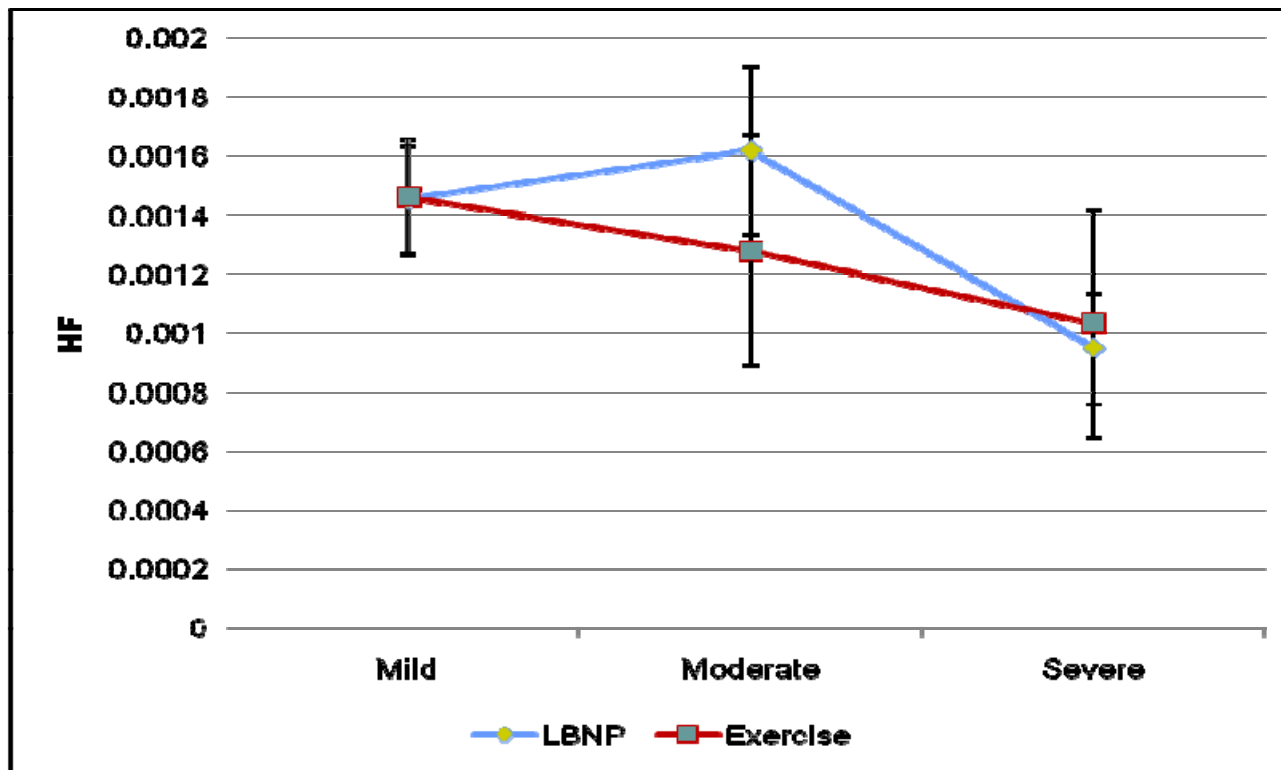
Comparison of DWT Measures for Three Classes - LBNP vs. Exercise



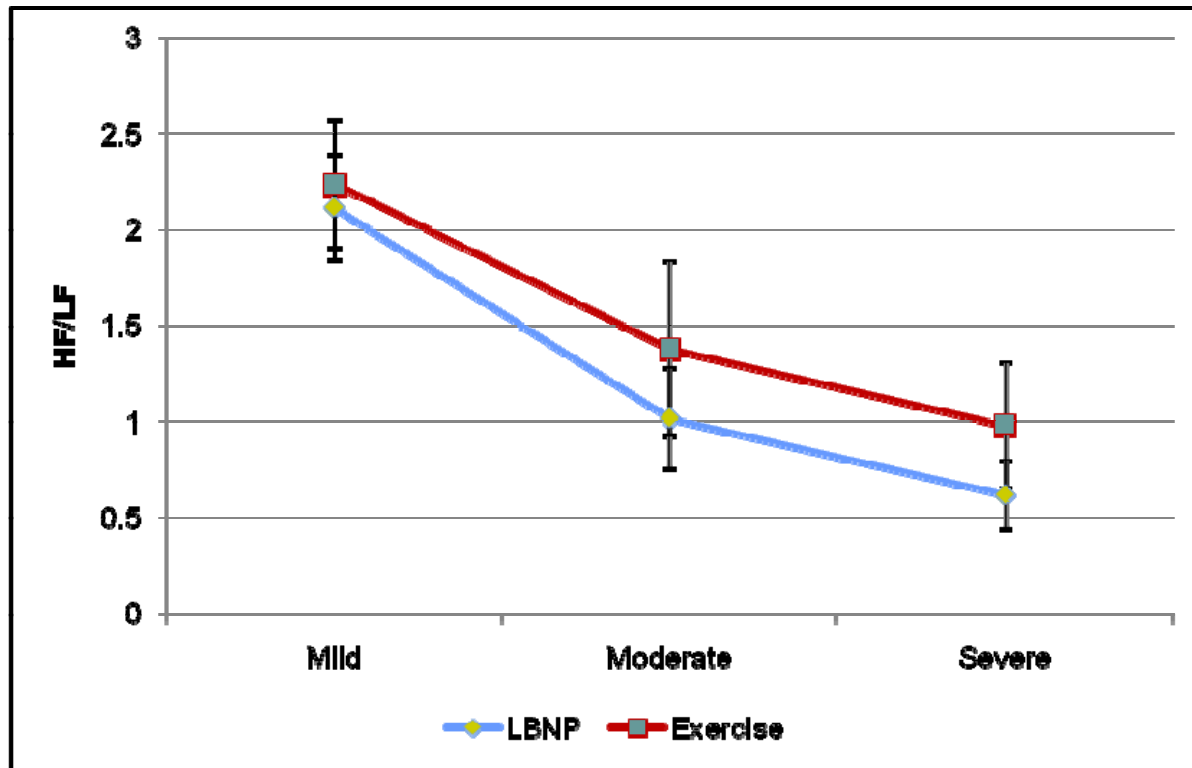
Comparison of DWT Measures for Three Classes - LBNP vs. Exercise (cont'd)



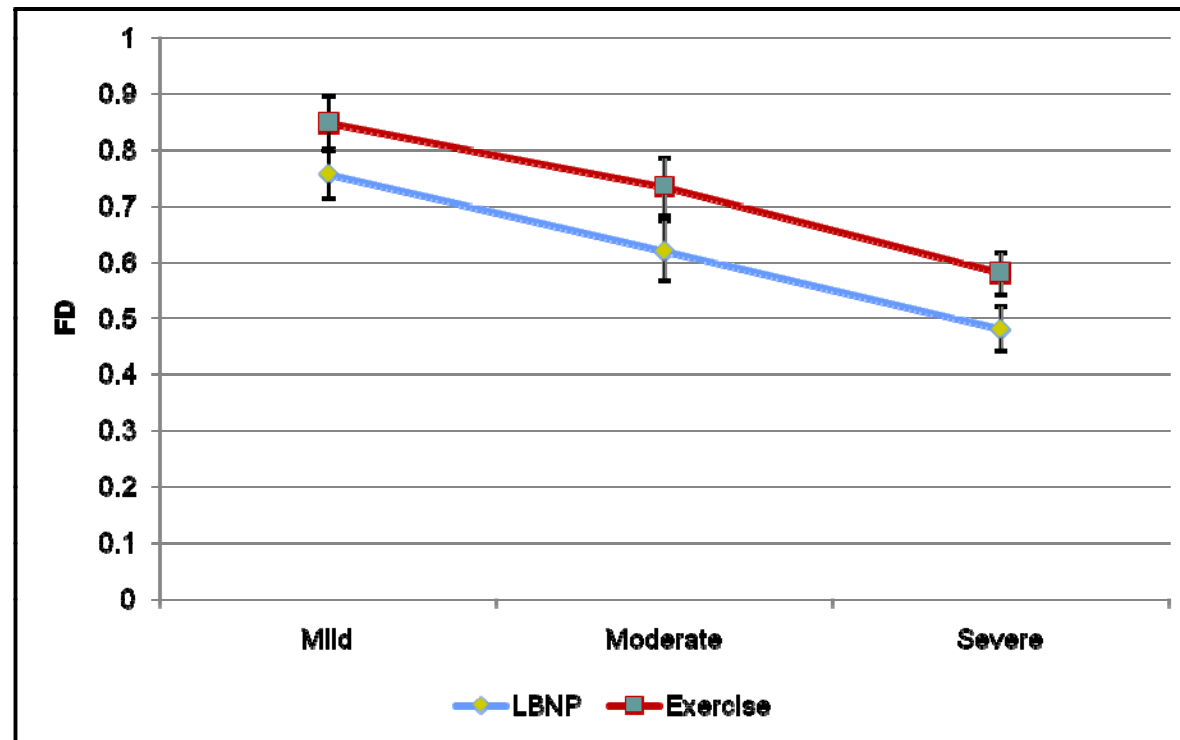
Comparison of PSD Measures for Three Classes - LBNP vs. Exercise



Comparison of PSD Measures for Three Classes - LBNP vs. Exercise (cont'd)



Comparison of FD for Three Classes - LBNP vs. Exercise



Study 2: Detection of Hemorrhage Severity using ECG and Other Physiological Signals



Analyzing ECG + Other Physiological Signals

ECG, Arterial BP, Impedance, and HRV extracted from ECG

ECG Data Provided from LBNP Subjects Studied by USAISR: Convertino, Ryan, Cooke, and Rickards.

Blood Loss Prediction with Machine Learning



- 2-minute recordings of ECG, HRV, Arterial BP, and impedance signals
- Each signal:
 - Non-Severe:152 cases
 - Severe:124 cases
- DWT with level 6 db4 is applied to ECG, ABP, and impedance signals directly and compared with incorporating HRV knowledge
- SVM was used for classification

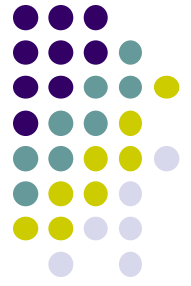
Prediction of Severe Cases (vs. Non-severe) with Knowledge of Baseline



Machine Learning with two class (Severe and Non-Severe)

Signal	Accuracy	Sensitivity	Specificity
HRV	89.5%	91.9%	86.8%
ECG	90.5%	90.3%	92%
ECG and impedance	92%	91.1%	92.2%
ECG and ABP	91%	90.2%	91%

Prediction of Severe of Cases (vs. Non-severe) without Knowledge of Baseline



Machine Learning with two class (Severe and Non-Severe)

Signal	Accuracy	Sensitivity	Specificity
HRV	76.8%	86.3%	68.4%
ECG	90%	88.9%	91.8%
ECG and impedance	91%	90%	92%
ECG and ABP	90.8%	89.7%	91.4%

TransCranial Doppler (TCD) for Prediction of Hemorrhage



	Accuracy	Average Precision	Average Recall
TCD	84.2%	84.1%	82.9%

Study 3: Implementation of Signal Processing System on a Mobile Armband Developed by BodyMedia, Inc.



Severity of Hemorrhage Prediction with Armband LBNP ECG

ECG Data Provided from LBNP Subjects Studied by USAISR and BodyMedia, Inc.



Armband LBNP Data

- 5-minute recording of ECG Signal
- Two classes (non-severe and severe)
 - Non-severe: 74 cases
 - Severe: 62 cases
- DWT with db4 level 6 is applied to ECG directly
- SVM was used for classification
- Sampling rate:128 Hz

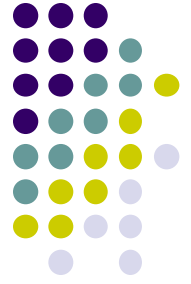




Prediction of Severe Cases

Machine Learning with two class (Severe and Non-Severe)

	Without Baseline Knowledge	With Baseline Knowledge
Accuracy	81.6%	86%
Sensitivity	75.8%	80.6%
Specificity	86.5%	90.5%



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