POLITECNICO DI MILANO

Cardiovascular response analysis in healthy and pathologic subjects during exercise

Valentina Magagnin

Introduction

Walking restoration / exercise: Important role in pathologic subjects

- Spinal Cord Injury
- Hemiparesis after stroke
- Heart Failure

Difficult exercise training performance

- Robotic Assisted treadmill Training with Body Weigth Support
- Light Cycloergometer Exercise

?? <u>Effects on the cardiovascular system</u>

Overview

Cardiovascular response during Rehabilitation Protocols

- Robotic Assisted treadmill Training
  - Experimental Protocols Identification
  - Signal Processing Methods
  - Results
- Light Cycloergometer Exercise → known cardiovascular modifications
  - Experimental protocol
  - Results
- Conclusions & Work in progress

Robotic - assisted Rehabilitation Technique

emerging rehabilitation technique for rehabilitation of patients with lost sensorimotor function

Advantages

- no **continuous manual assistance**
- partial **body weight support**
  - delayed muscle fatigue
  - strength, endurance and coordination recovery
- extremity muscles adaptation to increasing metabolic demand

Lokomat® (Hocoma Medical Engineering Inc., Zurich)

Robotic – assisted Rehabilitation Technique Background

Rehabilitation protocol:

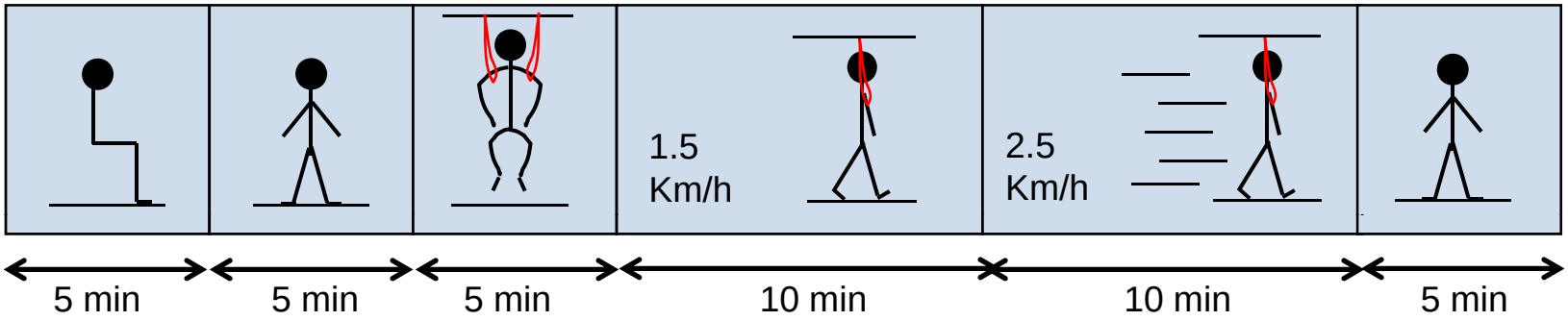
- 45 min walk sessions, **5 days/w for 6 weeks**
- Hips and legs instrumentation procedure into the Lokomat requires **subject suspension for about 5 min**

What about the **effects of the rehabilitation strategy** on the cardiovascular system in healthy and pathologic subjects?

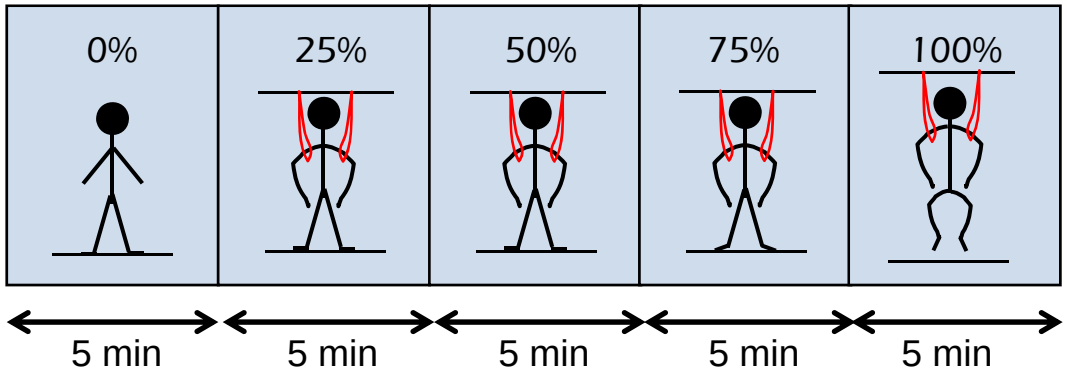
- Normal subjects
  - cardiovascular response evaluation
- Pathologic subjects
  - effects of the therapy on autonomic control system

Experimental protocols: Normal subjects

1. To investigate cardiovascular regulation during a traditional robotic-assisted locomotion protocol: (20 normal subjects, 25±3.8 yrs, 11M)



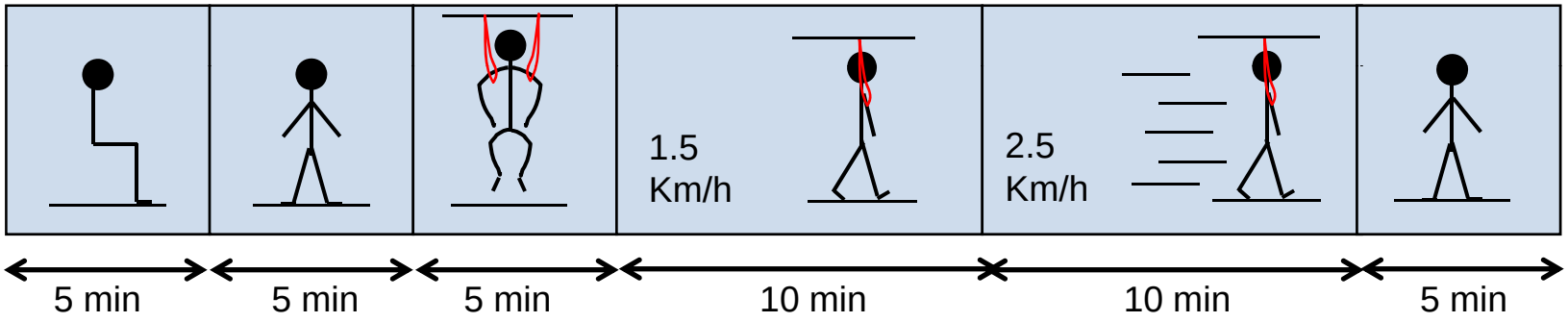
2. To evaluate the autonomic nervous system response during BWS : (10 normal subjects, 23±3.2 yrs, 7M)



Experimental protocols: Stroke survivors

1. To investigate the effects of BWS treadmill training on the autonomic regulation of heart rate: (5 subjects after stroke, 58±9 yrs, 5 M)

First & Last day of Lokomat treatment:



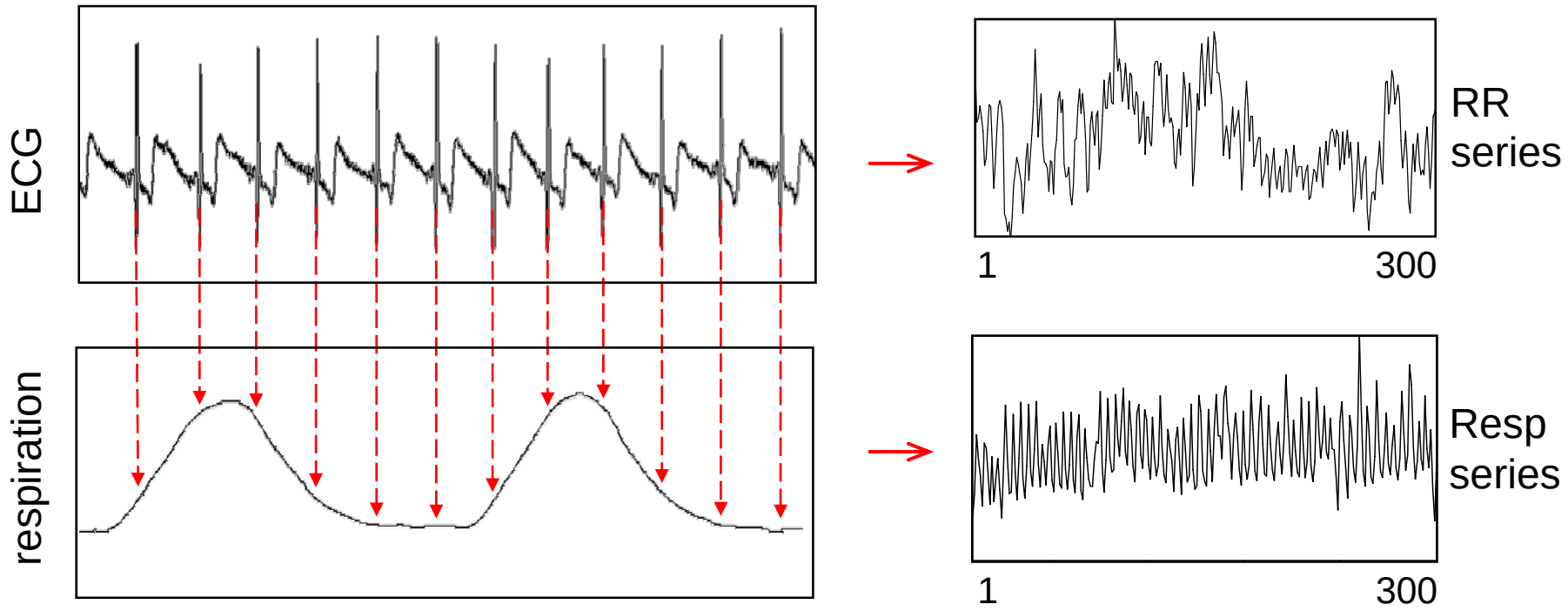
2. To investigate the gait improvement after Lokomat treatment

First & Last day of Lokomat treatment gait analysis

Signal Acquisition & Processing

Cardiac monitoring during body weight supported locomotion protocol (heart rate; parasympathetic and sympathetic modulation)

- I-lead ECG signal (f_s = 2048 Hz)
- Respiratory frequency signal (f_s = 256 Hz)



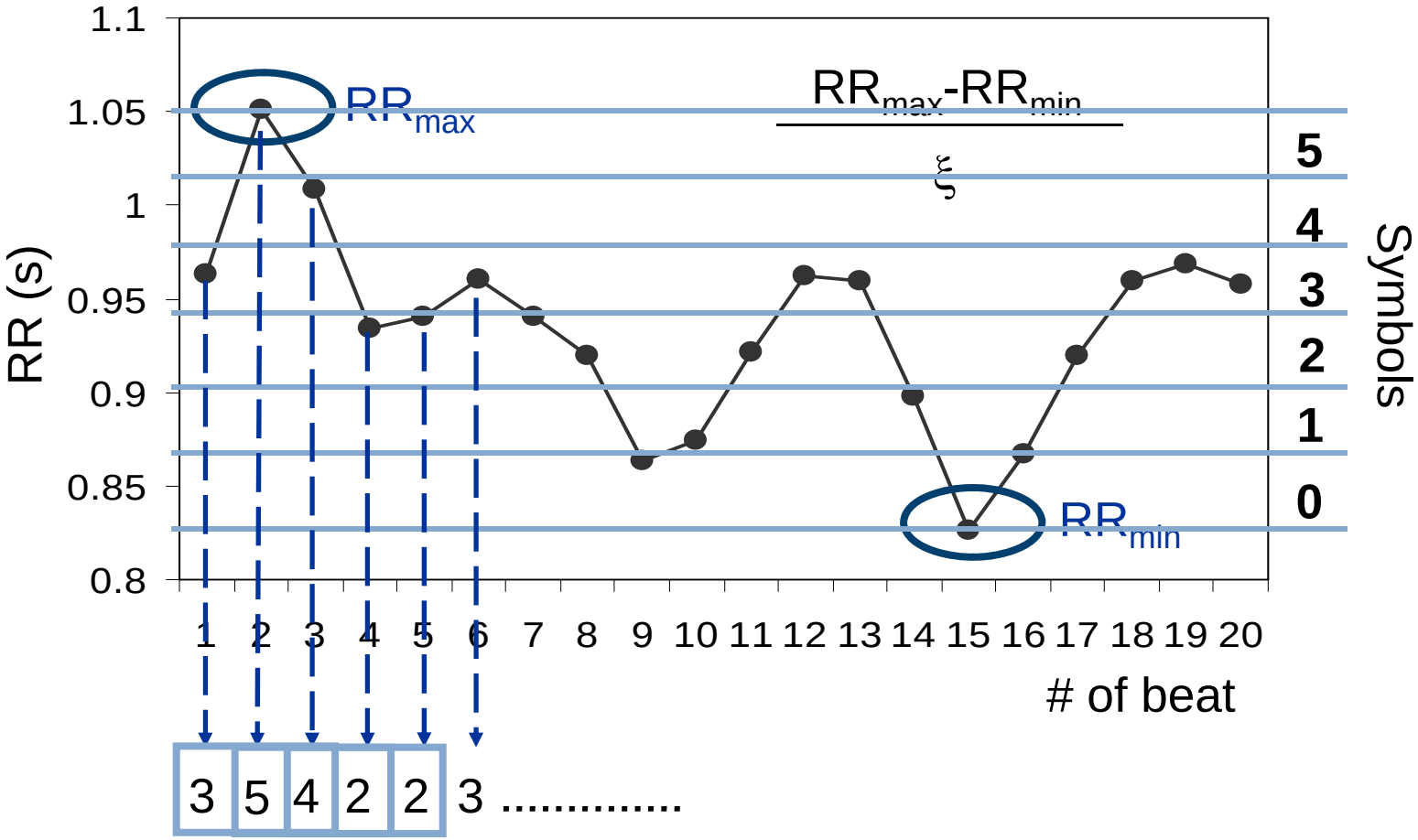
Methods:
Signal Processing Methods

- Spectral Analysis:
  - **AR method** *(Task Force '96)*

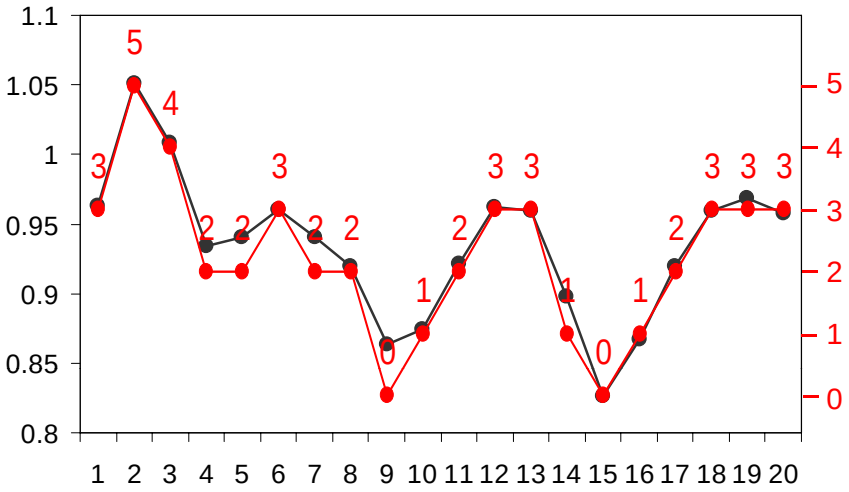
- Decomposition by means of waveforms:
  - **Symbolic Analysis**: 3 beats long patterns
    (Porta A et al, 2001, IEEE Trans Biomed Eng 48)
  - **Empirical Mode Decomposition**: Intrinsic Mode Functions
    (Huang NE et al, 1996, the Royal Society)

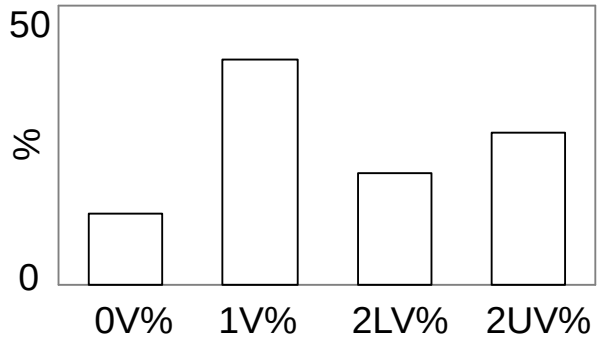
- Complexity analysis: to evaluate sympato-vagal balance
  - **Local Non-Linear Prediction method**
    (*Porta A et al, 2007, IEEE Trans Biomed Eng 54*)

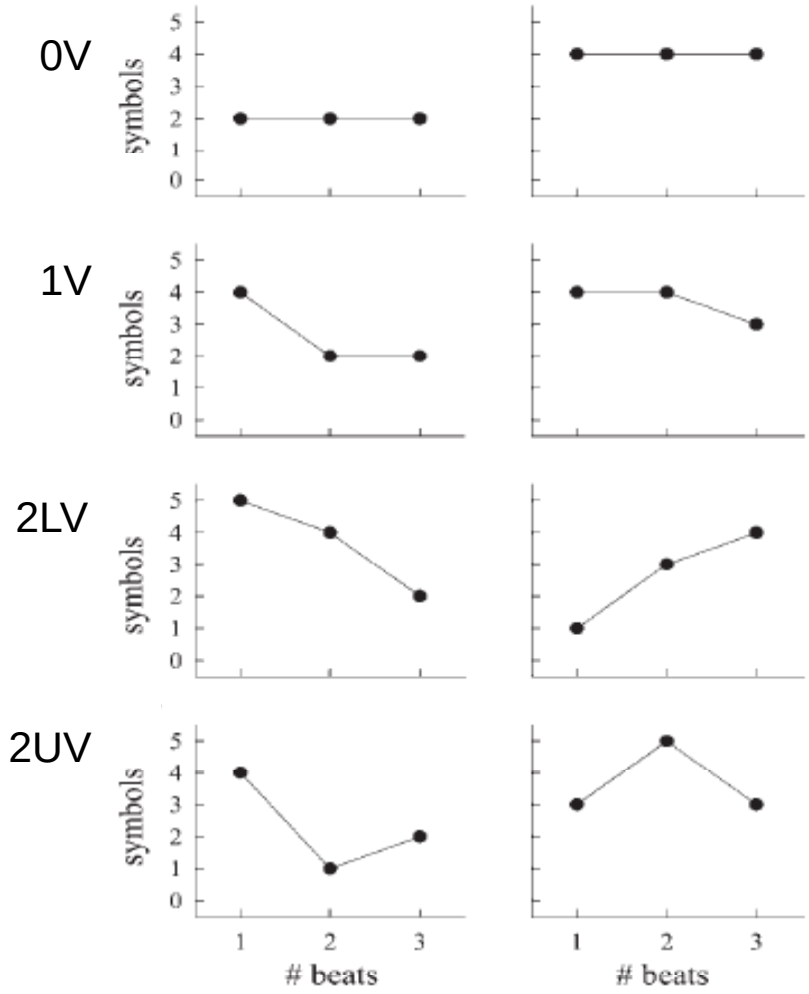
Methods:
Symbolic Analysis (1)



Methods:
Symbolic Analysis – Parameters Extraction







Porta A et al, 2001, IEEE Trans Biomed Eng 48

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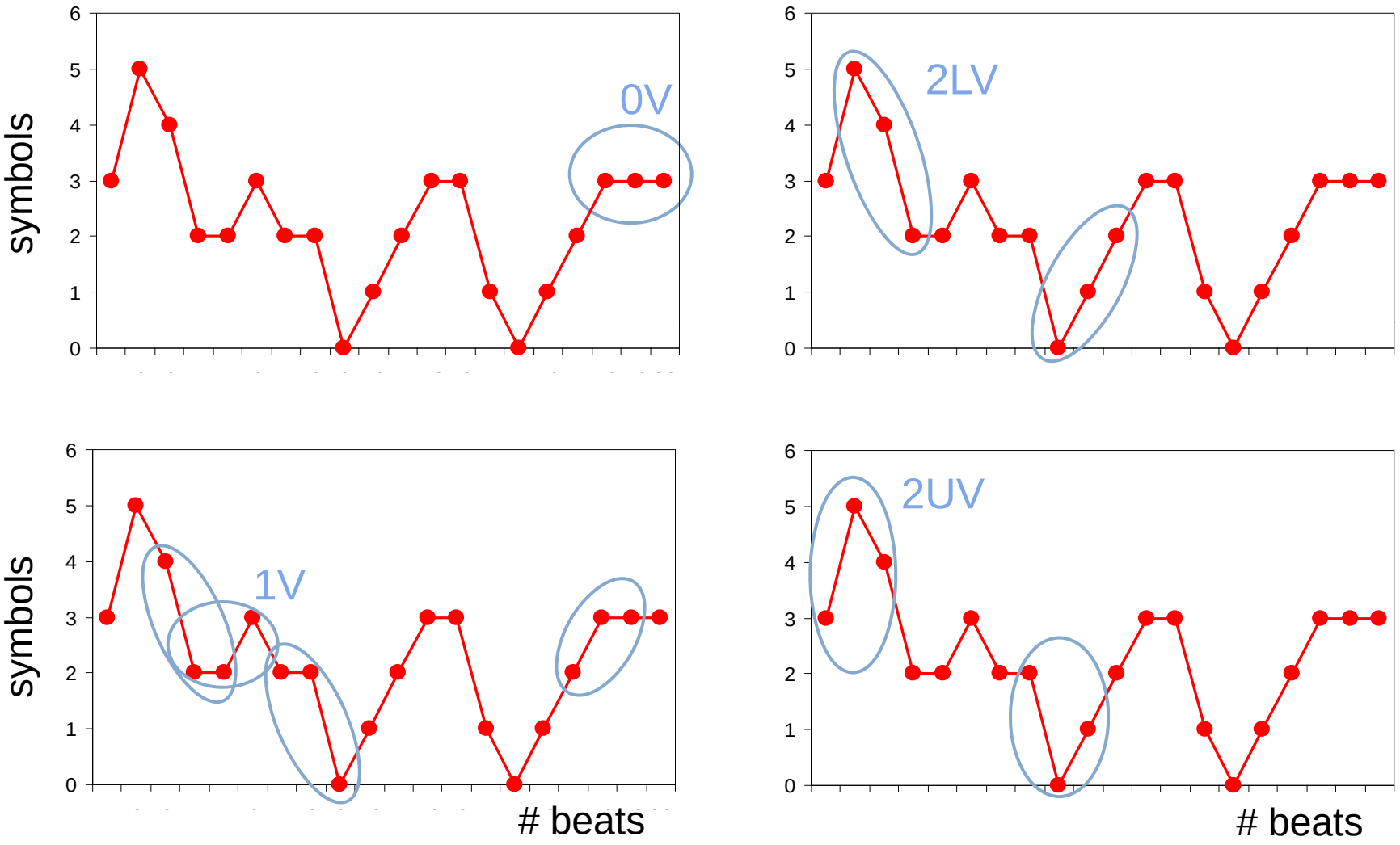


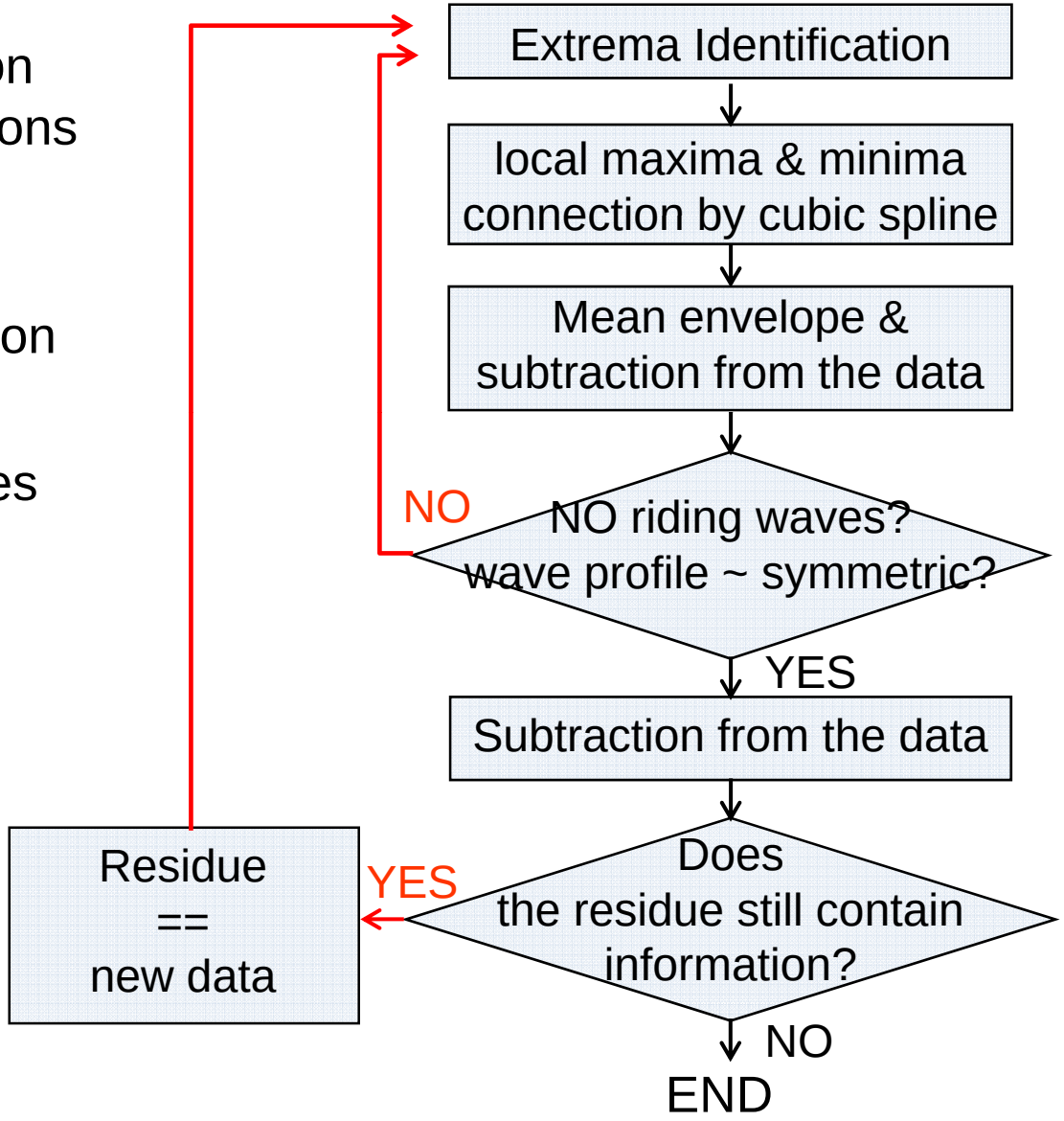
Methods:
Empirical mode decomposition (1)

Time series decomposition into Intrinsic Mode Functions

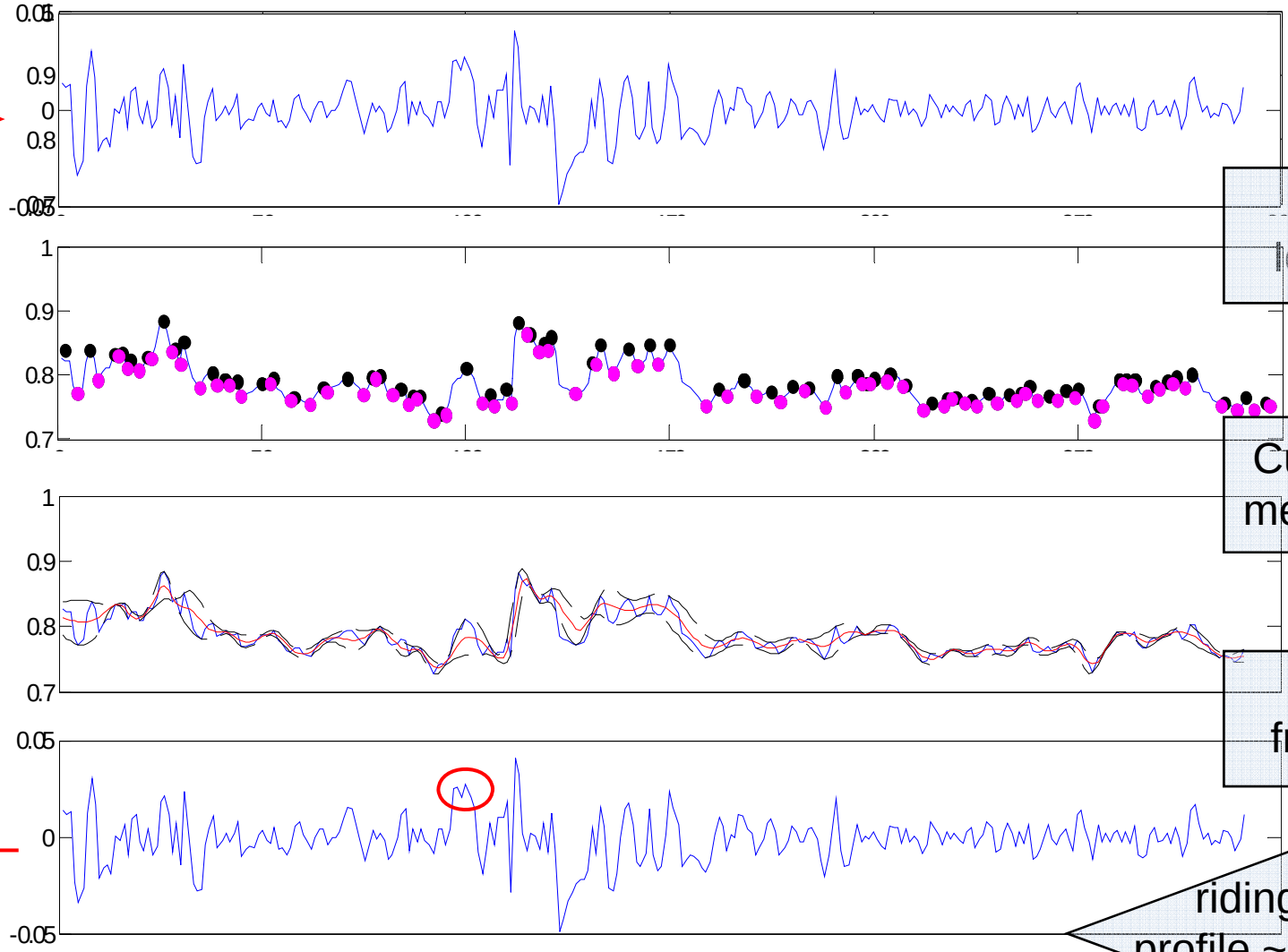
- Hilbert transform
- instantaneous frequencies calculation

Operator-independent identification of time scales

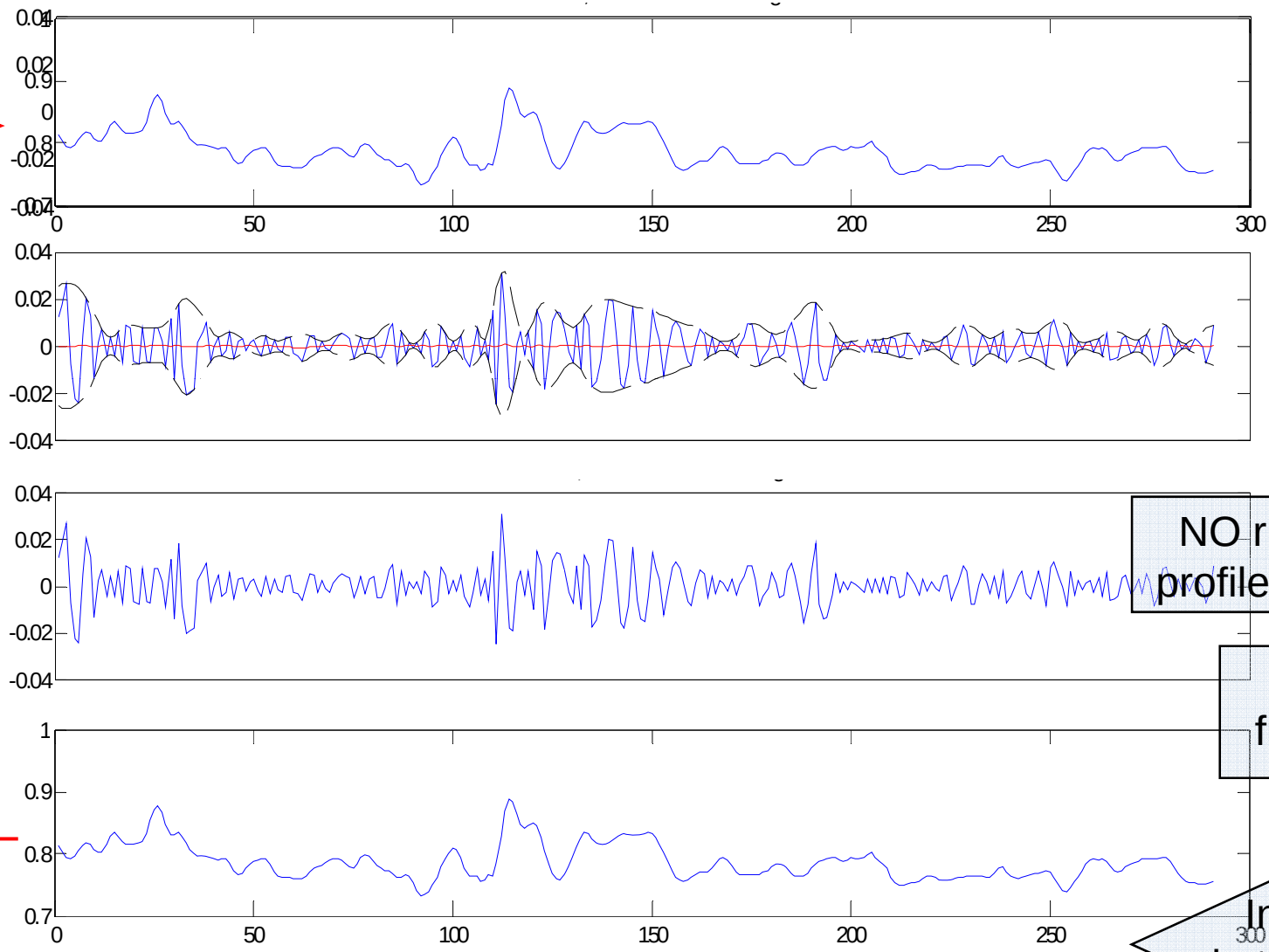
Physical meaning?



Methods:
Empirical mode decomposition (2)



Methods:
Empirical mode decomposition (2)



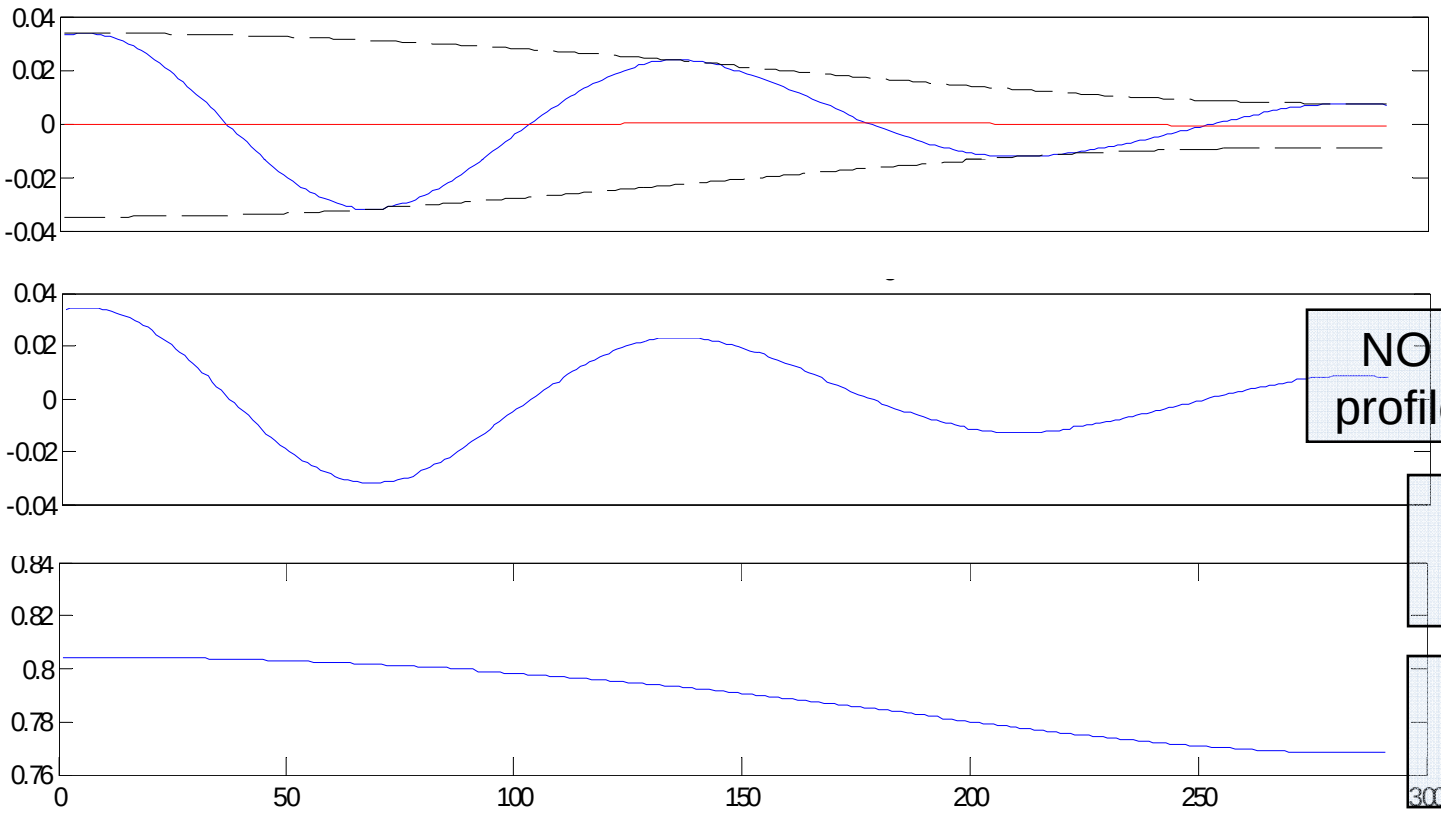
NO riding waves
profile ~ symmetric

subtraction
from the data

Information
in the residue?

Methods:
Empirical mode decomposition (2)

imf6

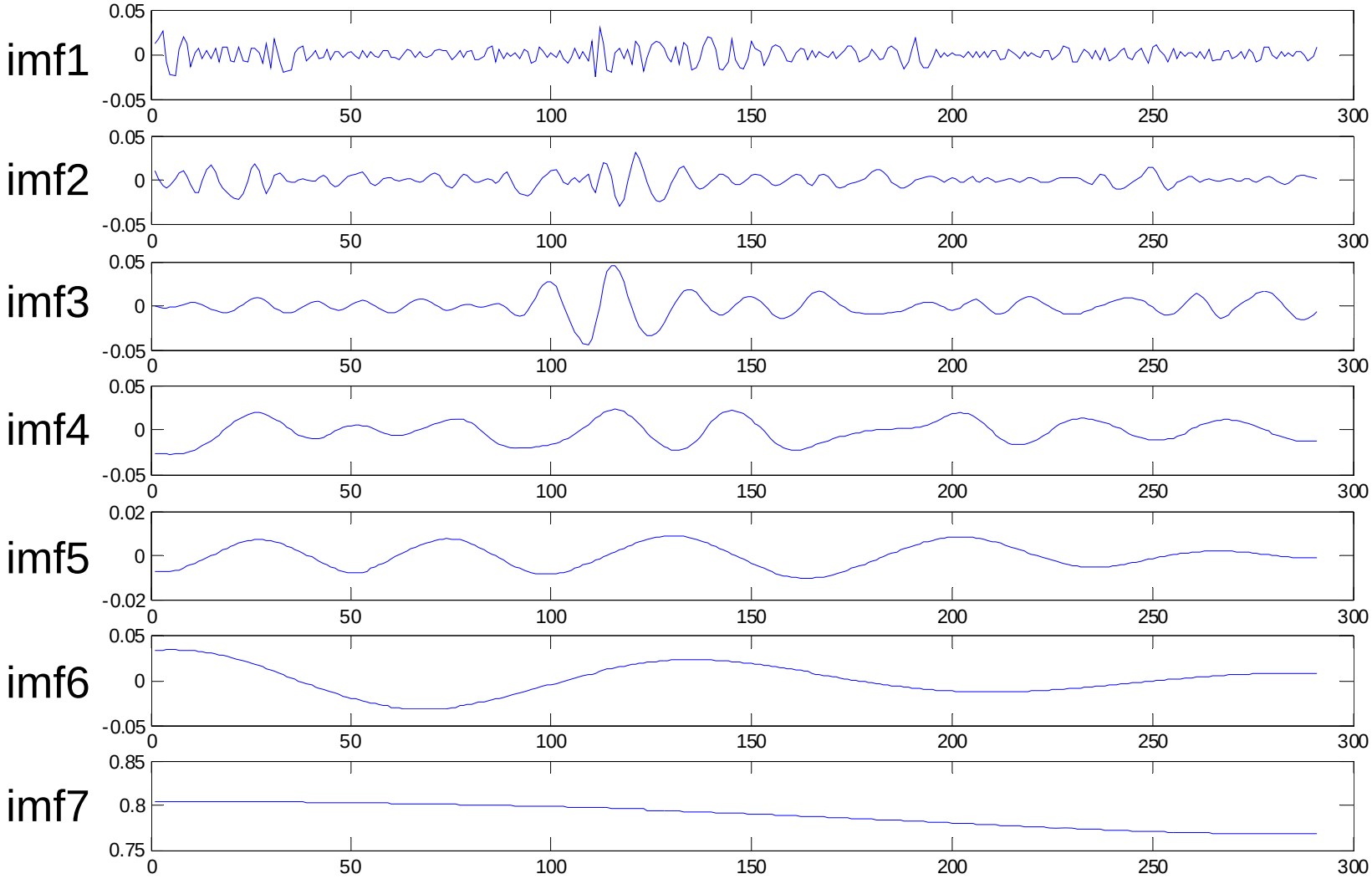


NO riding waves
profile ~ symmetric

subtraction
from the data

NO more information

Methods:
Empirical mode decomposition (2)

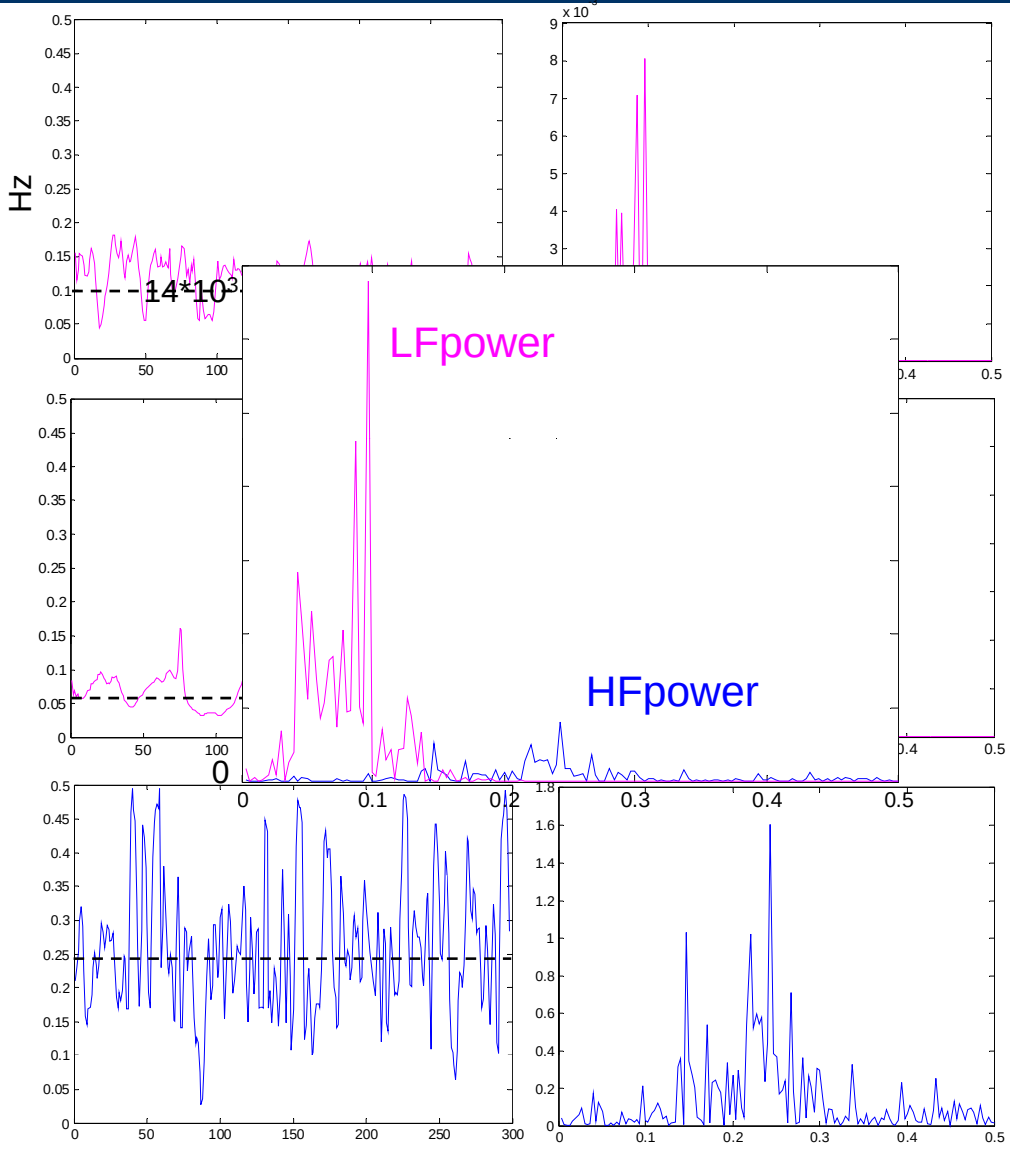


Methods:
EMD - Parameters Extraction (1)

LF1: First mode with characteristic frequency closest to 0.1 Hz

LF2: First mode with characteristic frequency lower than LF1 (LF band?)

HF*i*: Modes with characteristic frequencies greater than LF1



Methods:
Local non-linear prediction

Definition:

Patterns with similar past values have close future values

Hypotesis:

$\exists$ a continuous function: $x(i+1) = f(x_L(i))$

$x_L(i) = (x(i), x(i-\tau), ..., x(i-(L-1)\tau))$

The continuity guarantees that: if $x_L(i),\ x_L(j)$ are close

=> $x(i+1),\ x(j+1)$ will be close

Patterns similarity criterion?

$x_L(j)$ is close to $x_L(i)$ if $x_L(j)$ stays in the same finite region of the phase space that contains $x_L(i)$

$\Rightarrow$ The estimated function can be used to predict future values

Local Approximation technique:

$\hat{x}_L(i+1/L) = \hat{f}(x_L(i))$

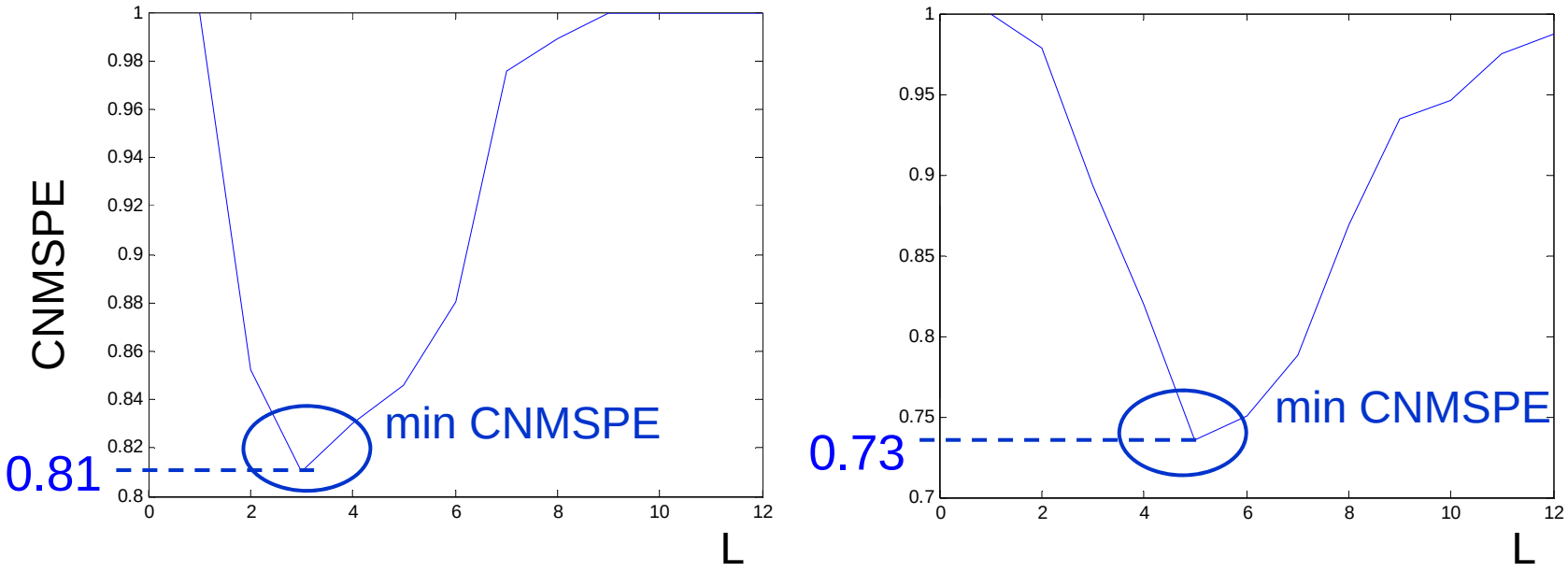
Methods:
Local non-linear prediction

Cost function for Evaluating Prediction:

$\hat{f}()$ → Prediction error $e(i/L-1) = x(i) - \hat{x}(i/L-1)$

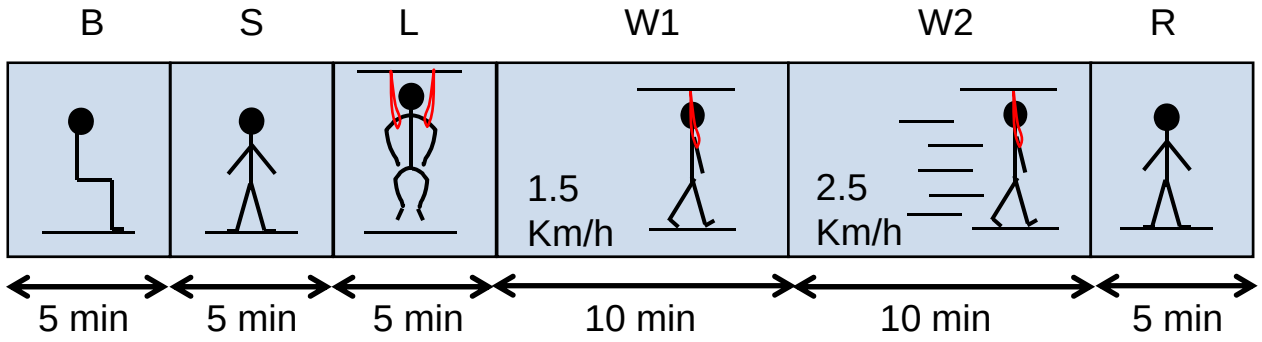
→ Normalized Mean Squared prediction error

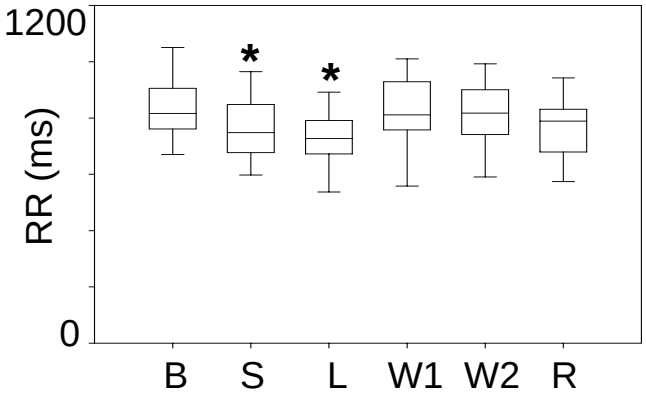
→ correction to avoid the " perfect prediction" effect (L ↑)

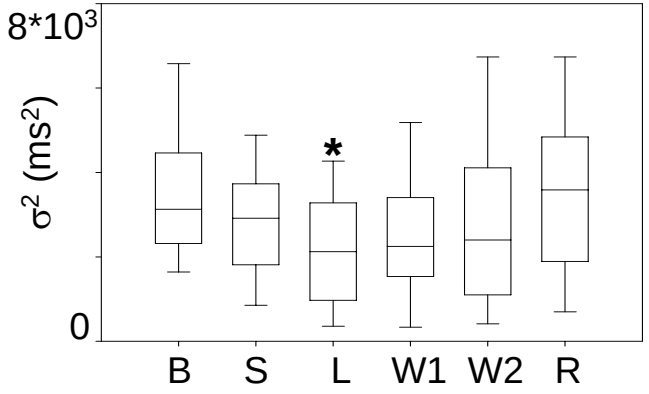


UPI=min(CNMSPE(L))

Results:
Normal Subjects: Protocol #1



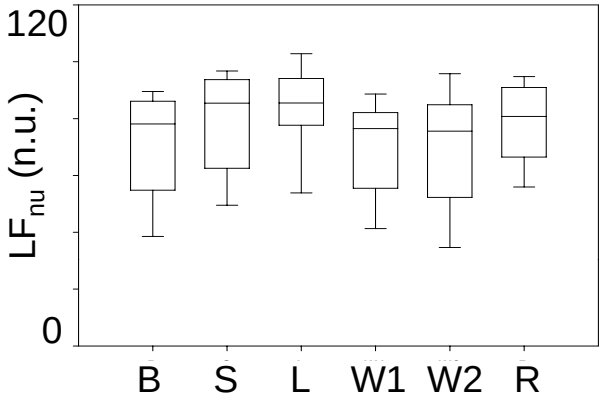


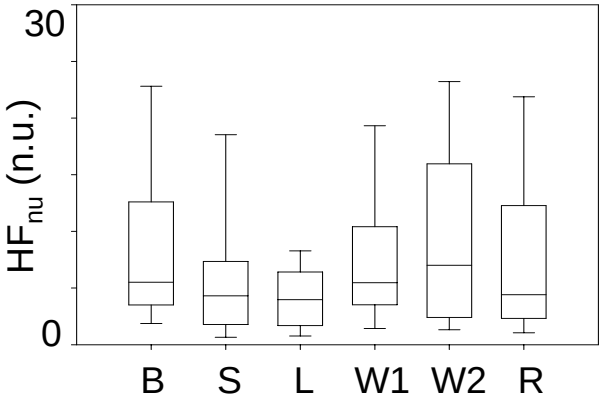


* $p<0.05$ vs B

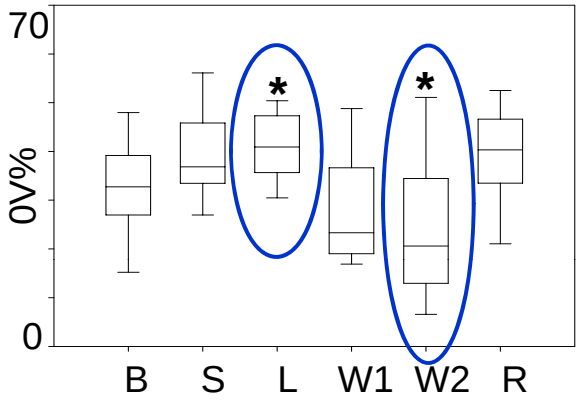
Results:
Normal Subjects: Protocol #1

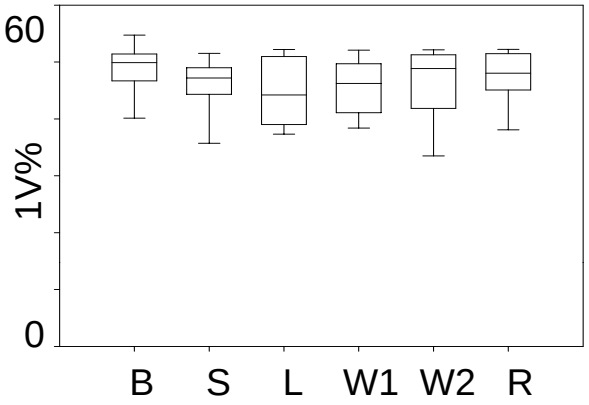
Spectral Analysis

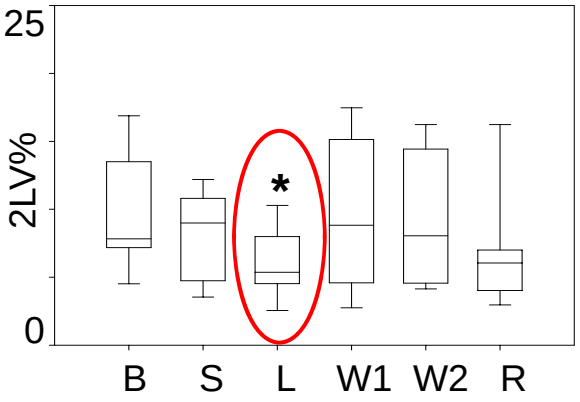


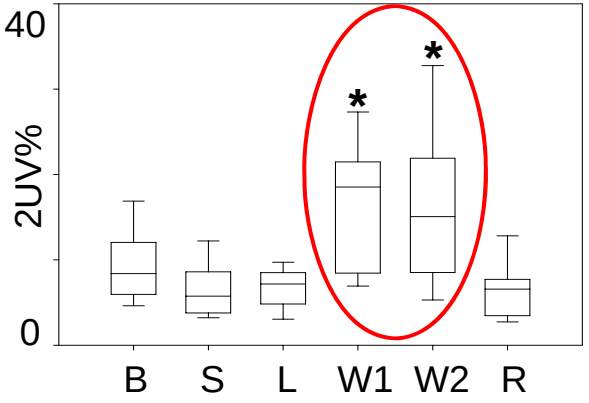


Symbolic Analysis









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Results:
Normal Subjects: Protocol #1

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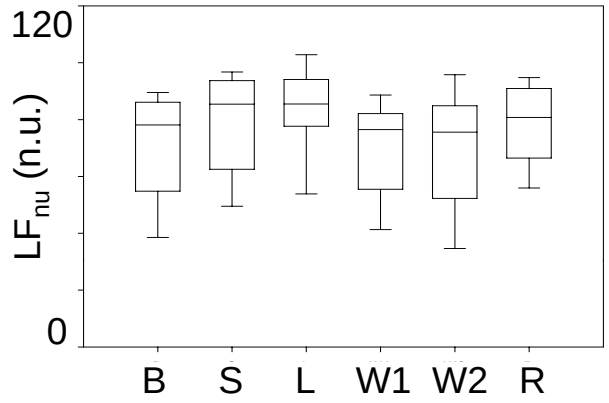
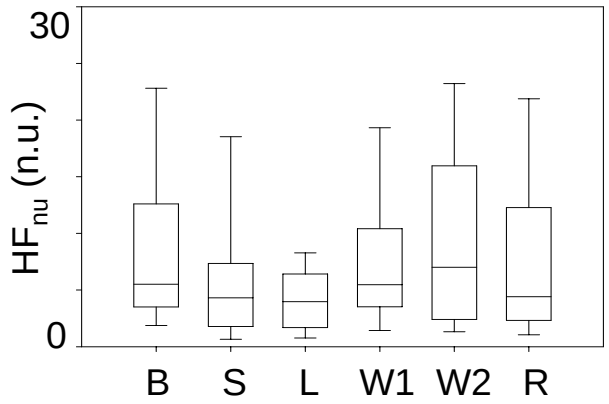
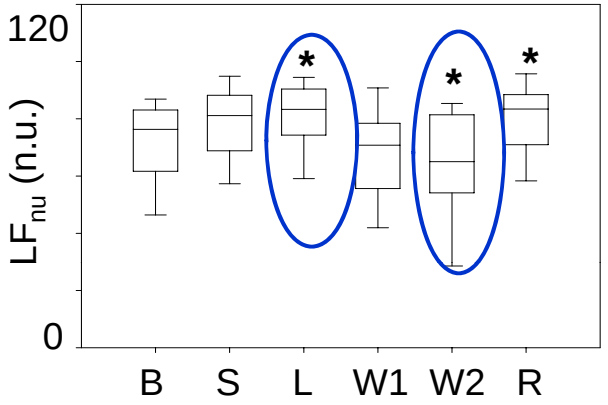
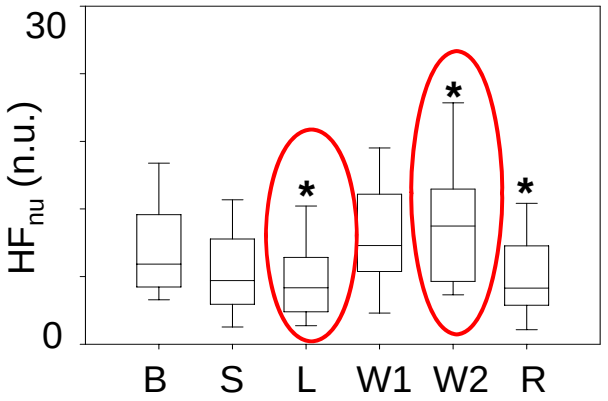




EMD Analysis





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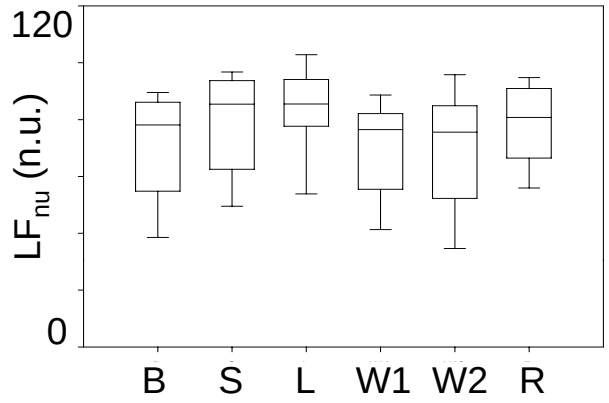
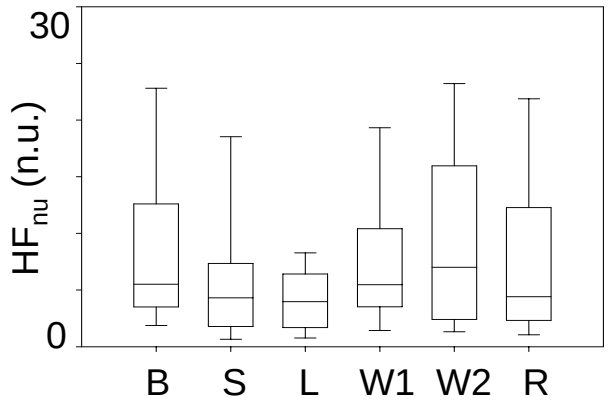
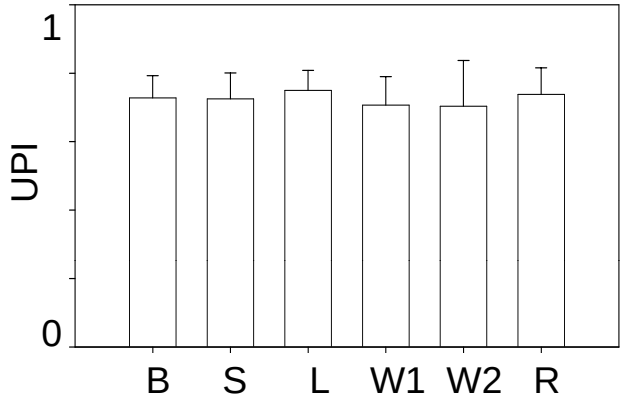
Results:
Normal Subjects: Protocol #1

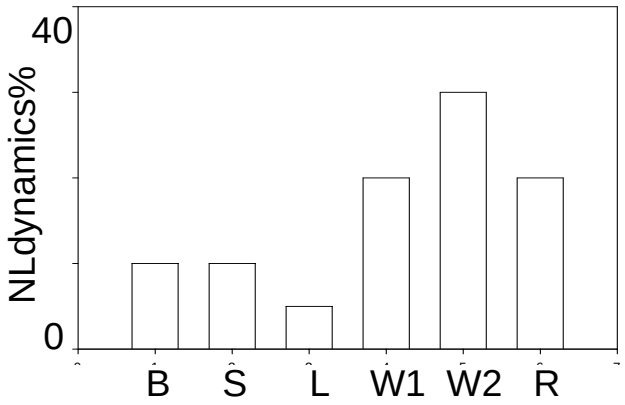
Spectral Analysis





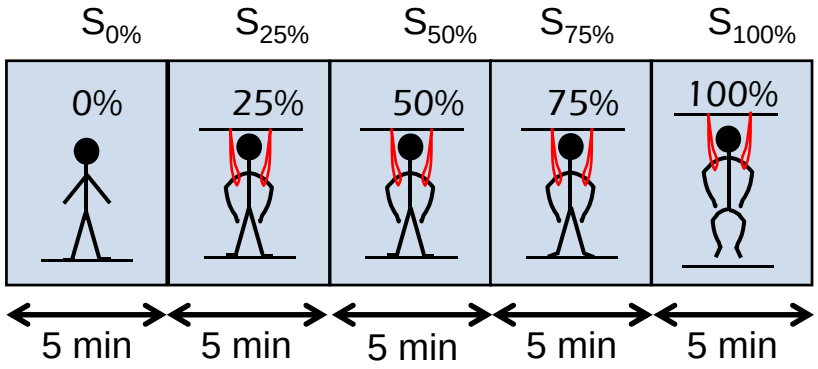
Complexity Analysis

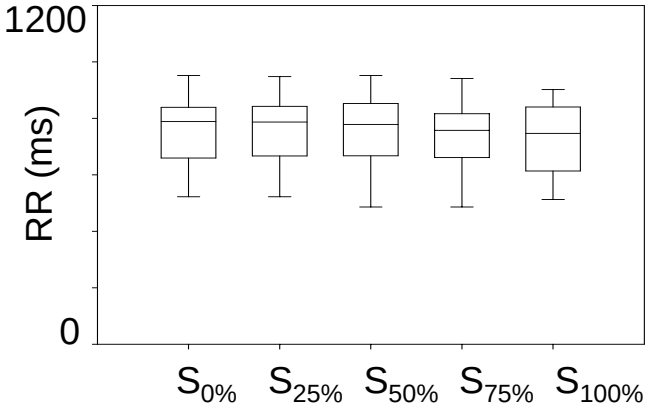


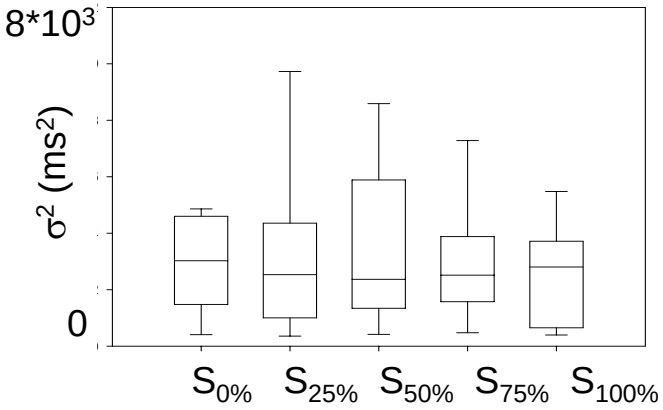


* p<0.05 vs B

Results:
Normal Subjects: Protocol #2

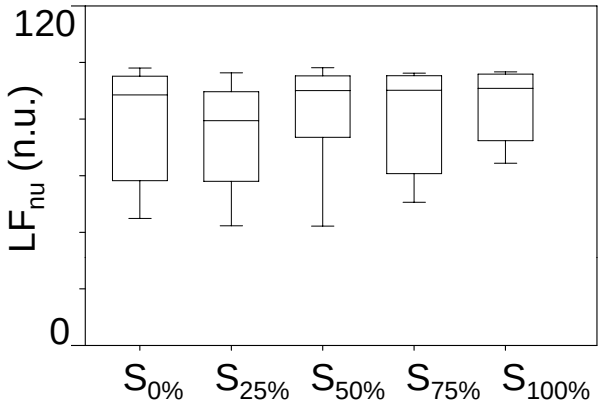


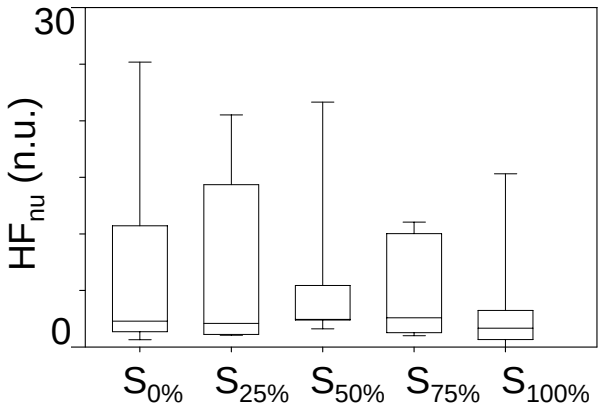




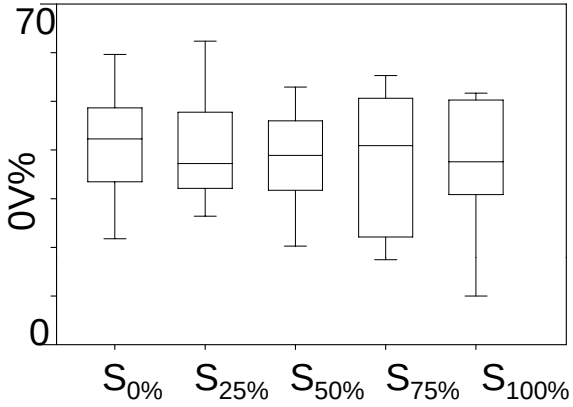
Results:
Normal Subjects: Protocol #2

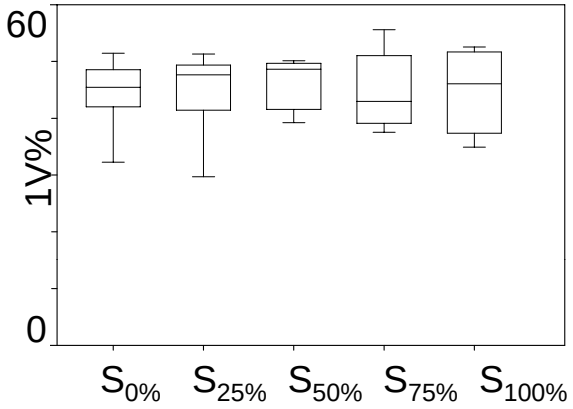
Spectral Analysis

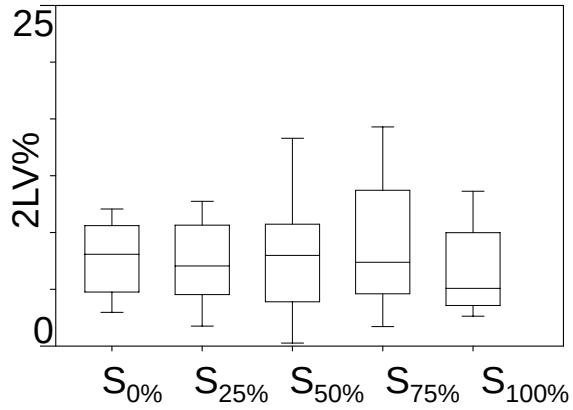


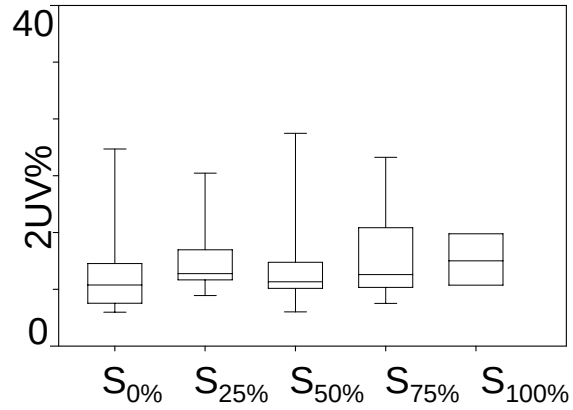


Symbolic Analysis



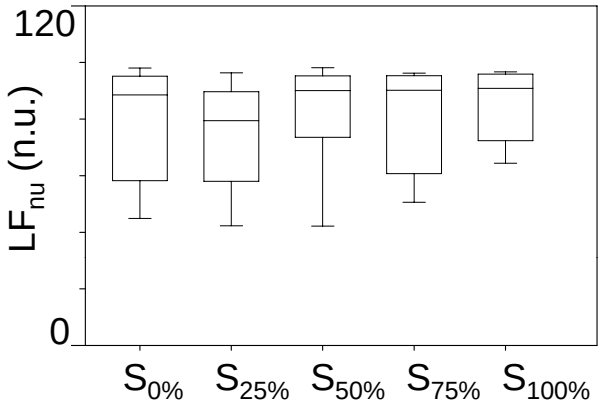


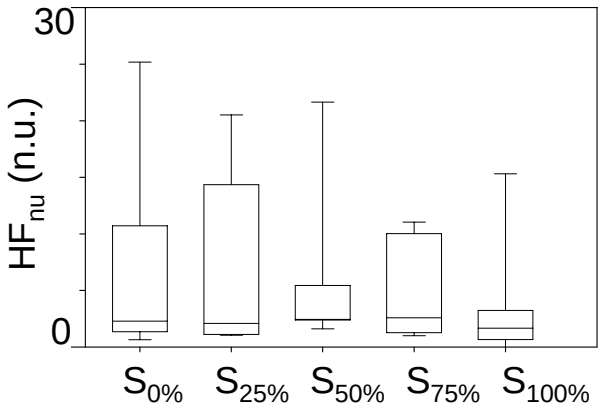




Results:
Normal Subjects: Protocol #2

Spectral Analysis





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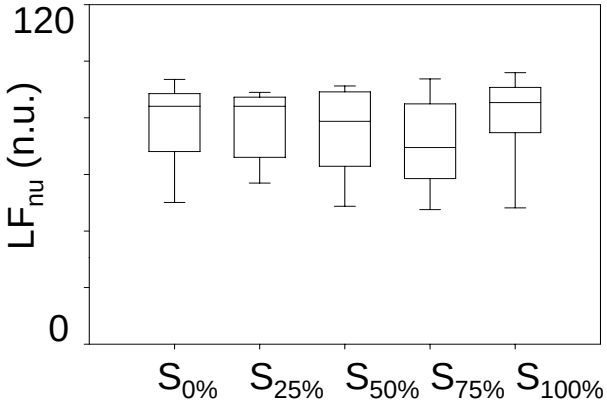
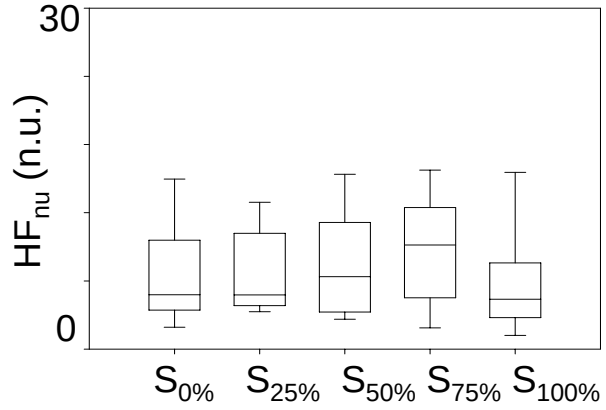
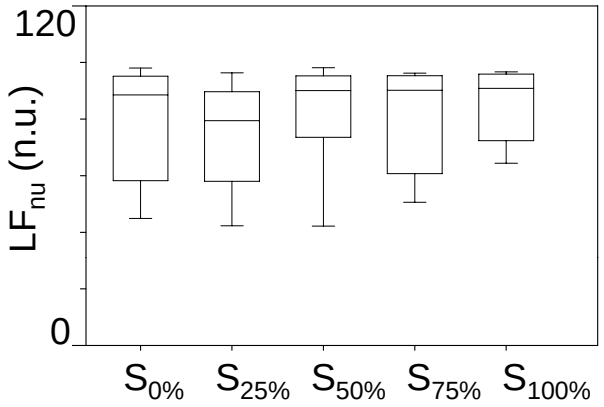
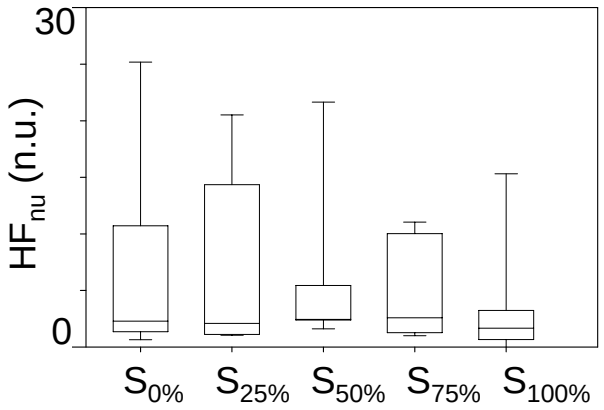




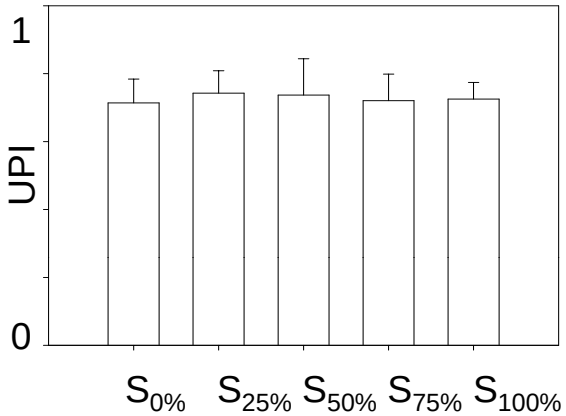
Results:
Normal Subjects: Protocol #2

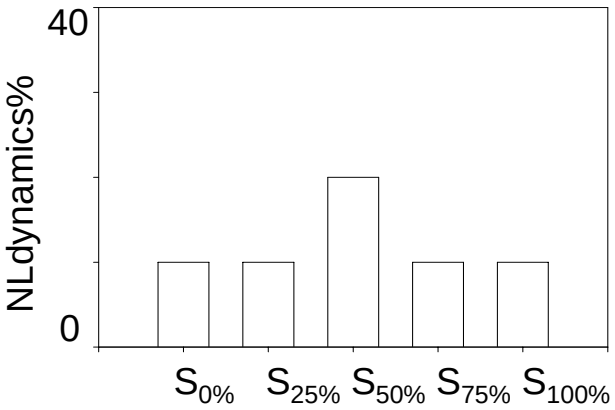
Spectral Analysis



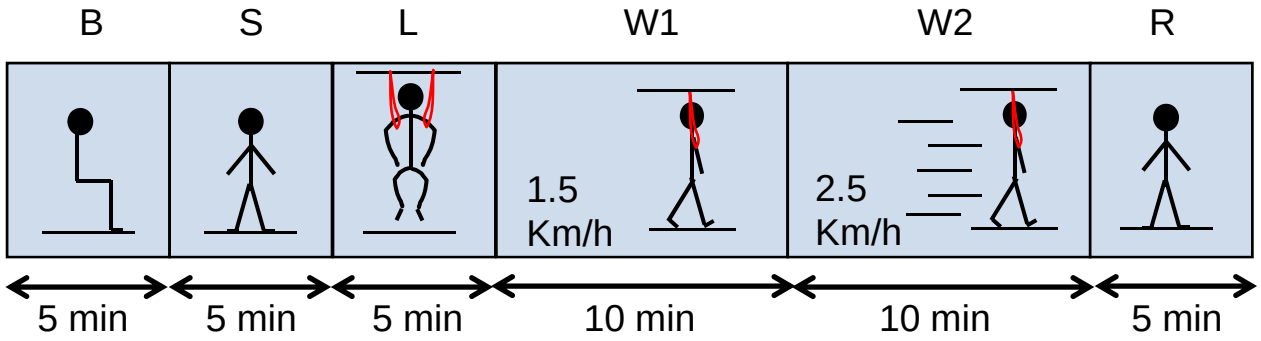


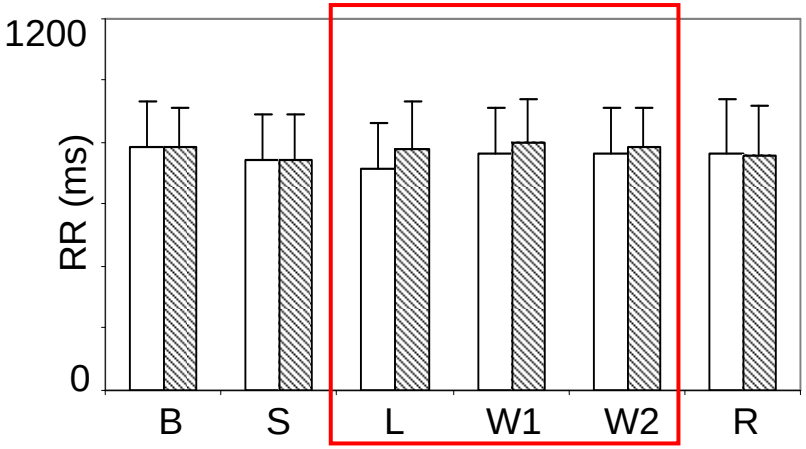
Complexity Analysis

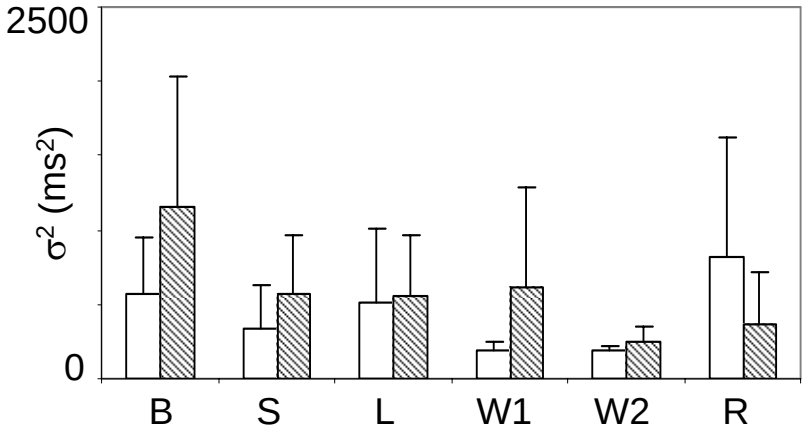




Results:
Subjects after Stroke





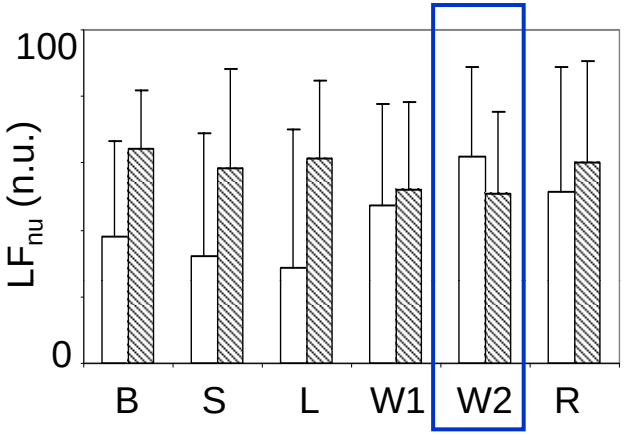


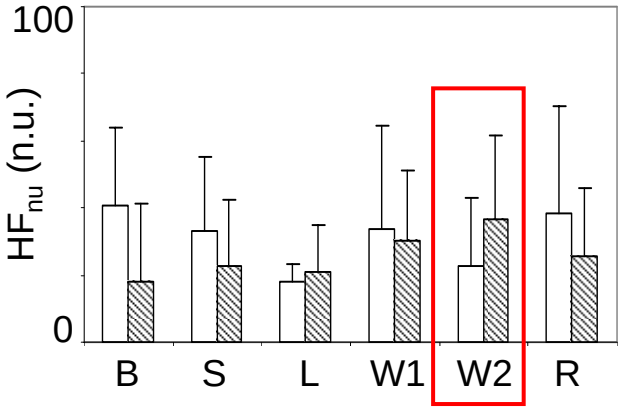
First Lokomat treatment

Last Lokomat treatment

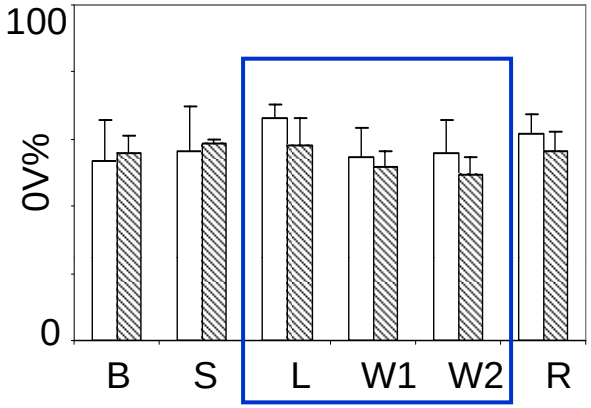
Results:
Subjects after Stroke

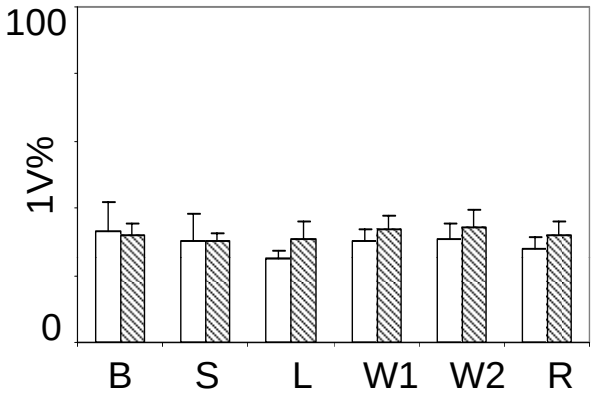
Spectral Analysis

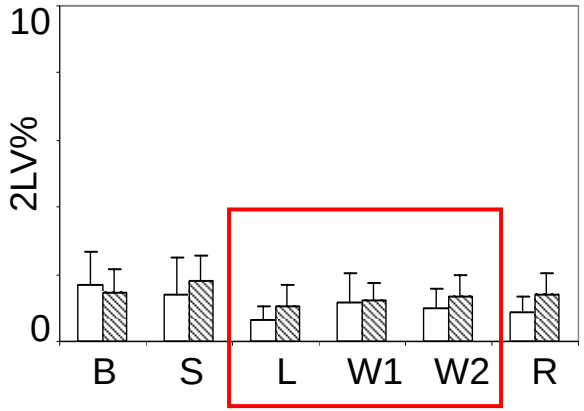


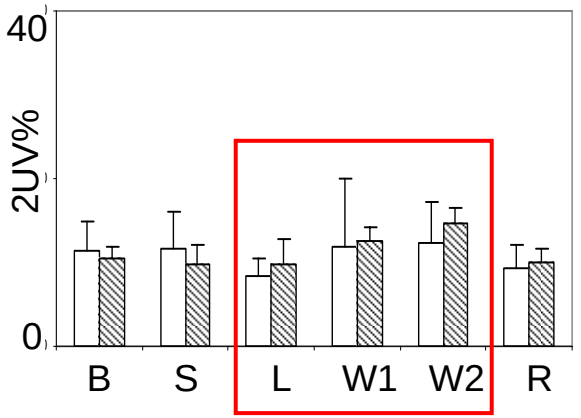


Symbolic Analysis



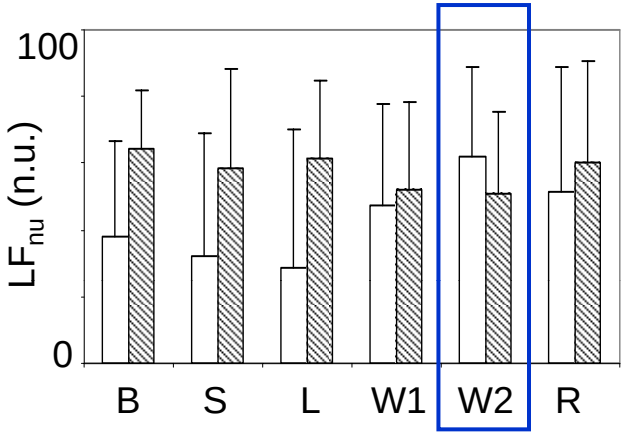


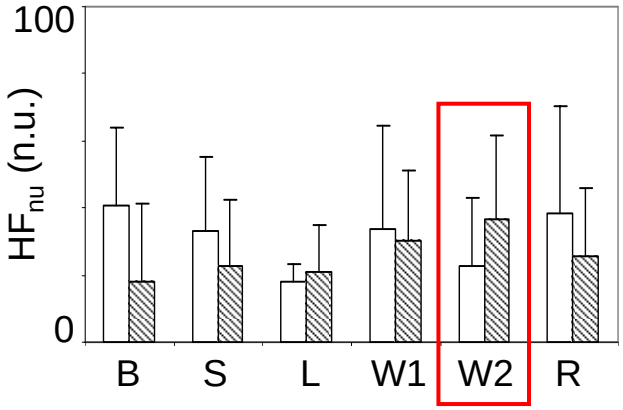




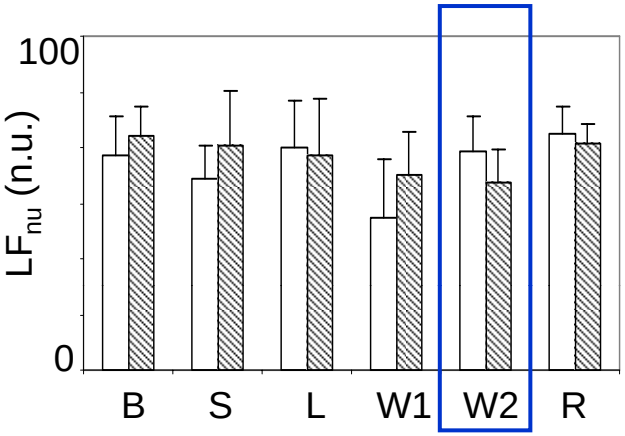
Results:
Subjects after Stroke

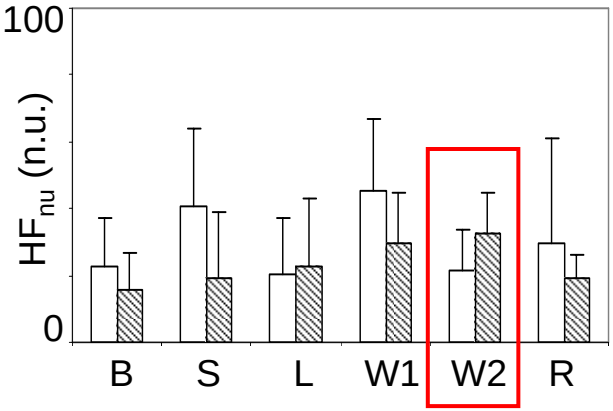
Spectral Analysis





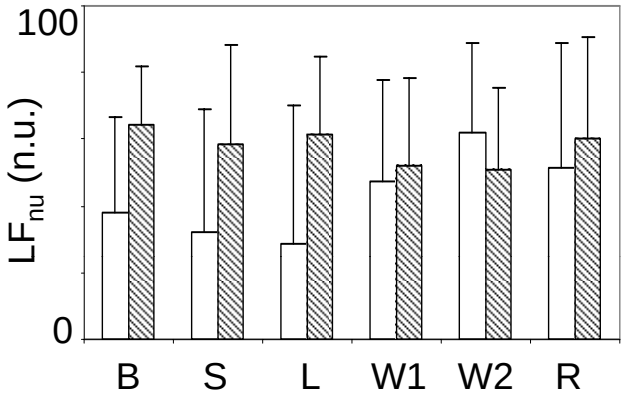
EMD Analysis

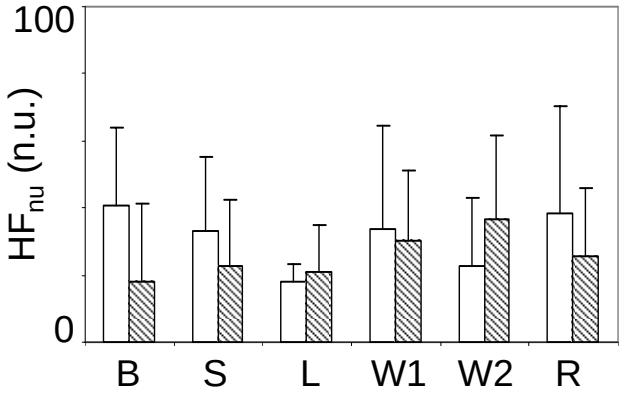




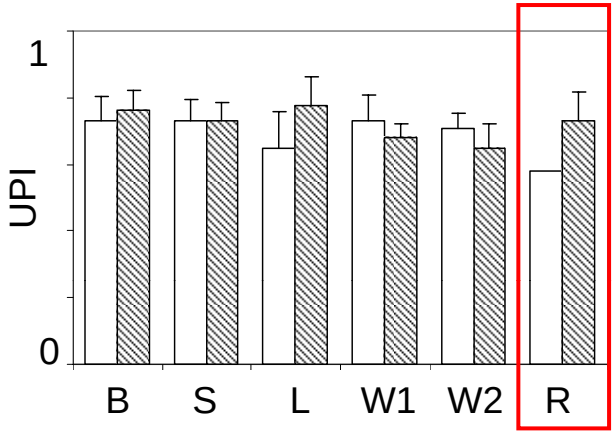
Results:
Subjects after Stroke

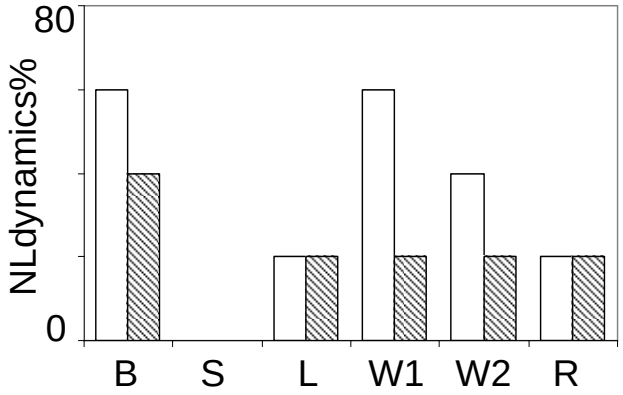
Spectral Analysis





Complexity Analysis





Exercise protocol:

12 healthy subjects

Data Acquisition:

ECG & respiratory signals

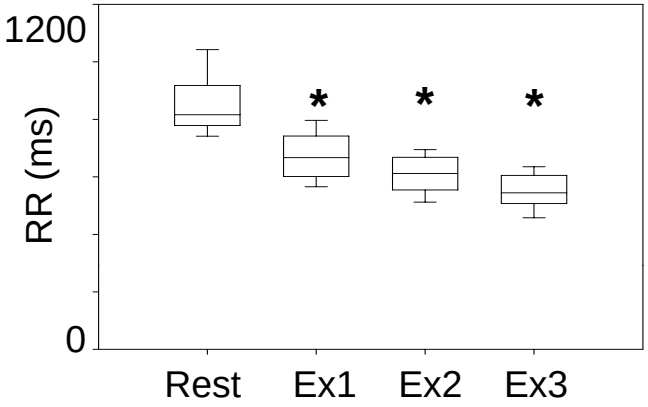
Arterial pressure (non invasive)

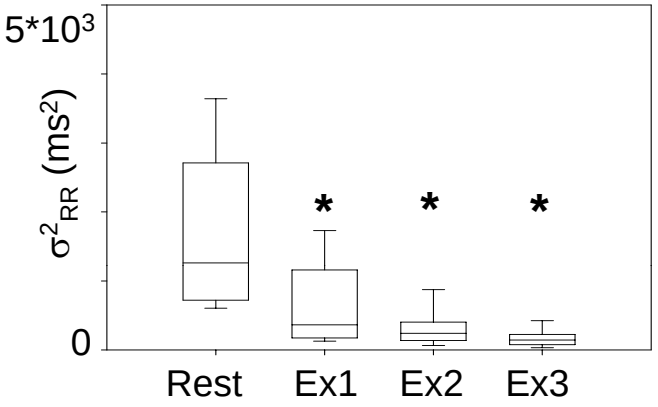
Experimental Protocol:

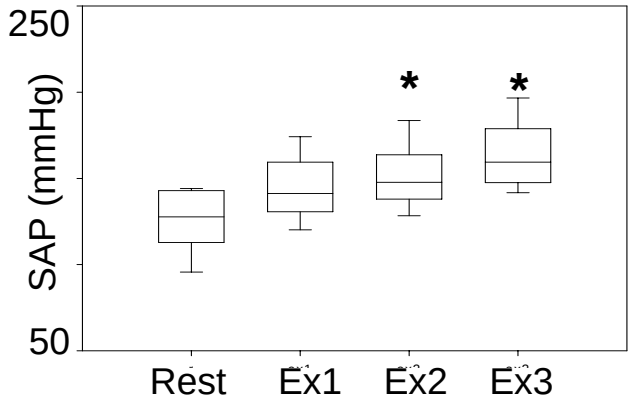
- Rest → 10 min baseline recording (supine)
- Three-step progressive supine bicycle exercise
  - Ex1 → 10%
  - Ex2 → 20%
  - Ex3 → 30%

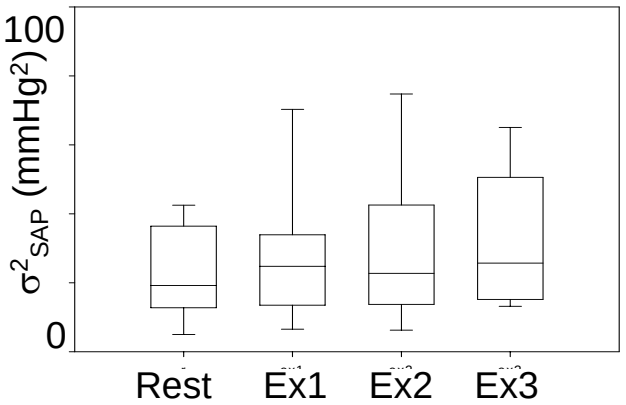
} nominal maximum exercise

Results:
Exercise protocol





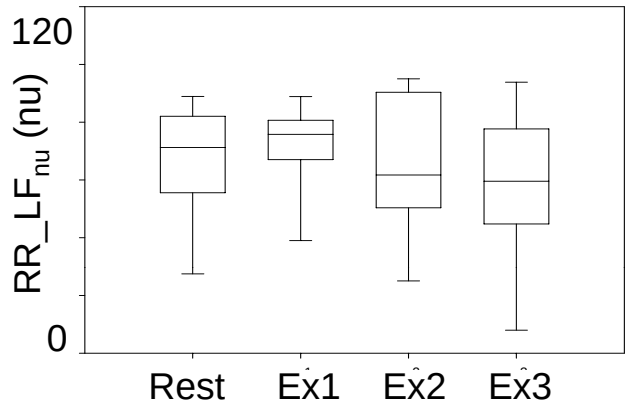


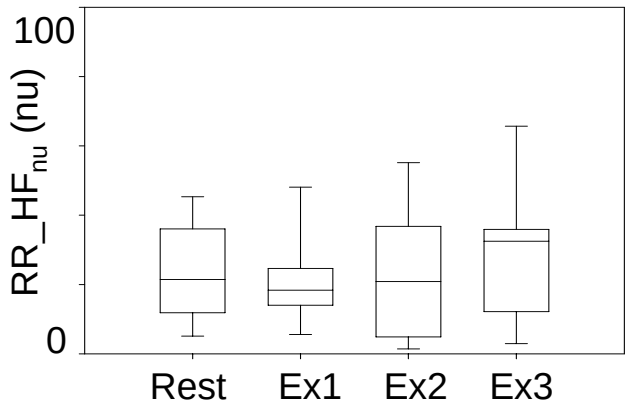


* $p<0.05$ vs rest

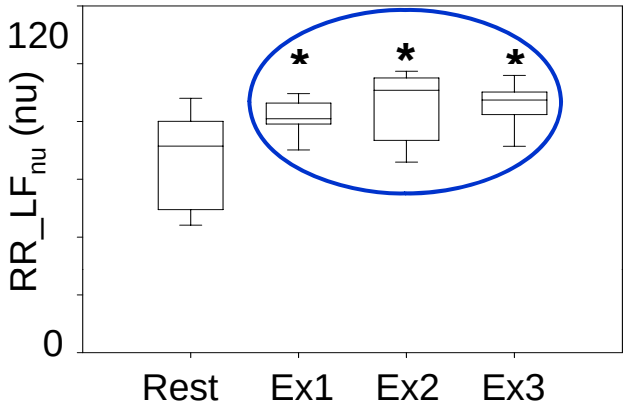
Results - RR: Exercise protocol

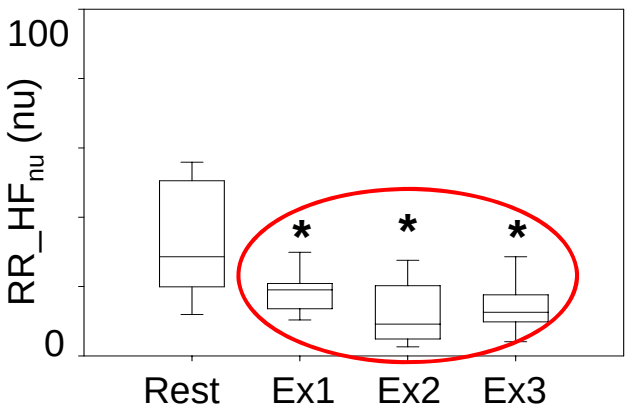
Spectral Analysis





EMD Analysis

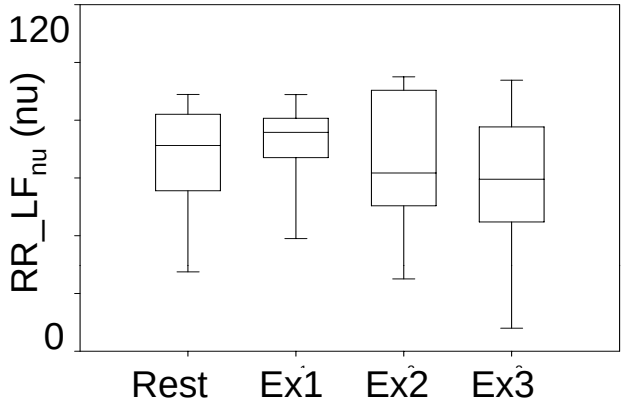


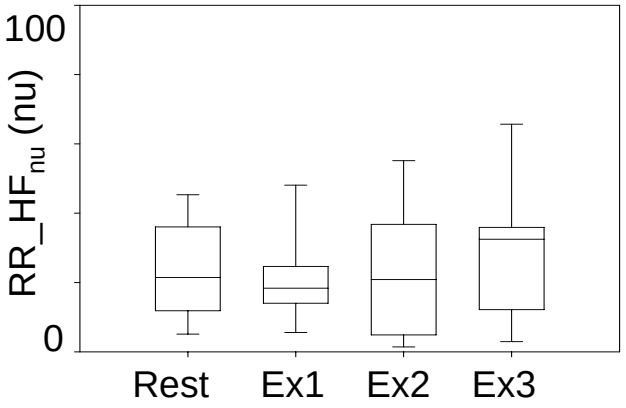


* $p<0.05$ vs rest

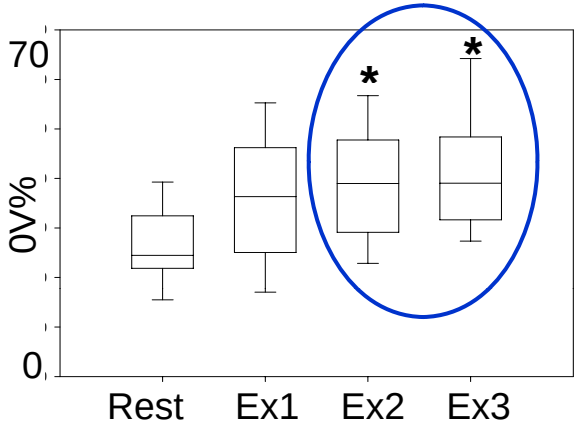
Results - RR: Exercise protocol

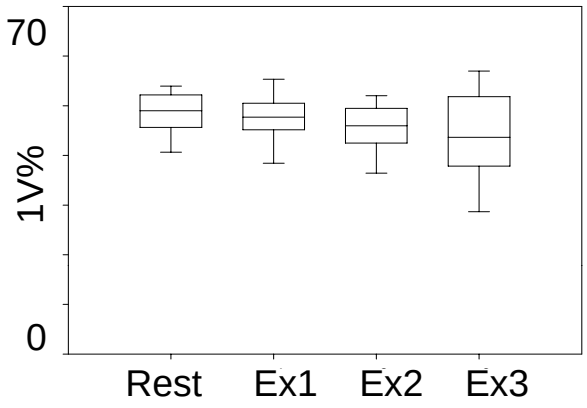
Spectral Analysis

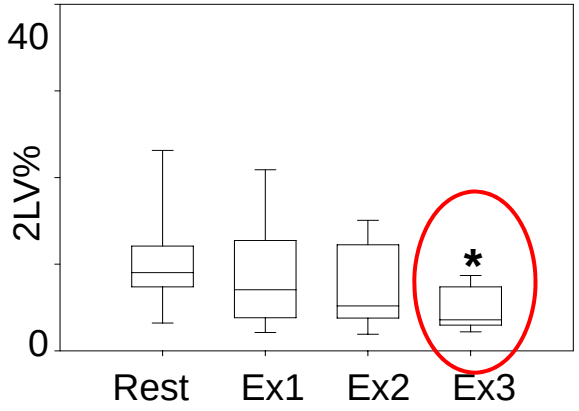


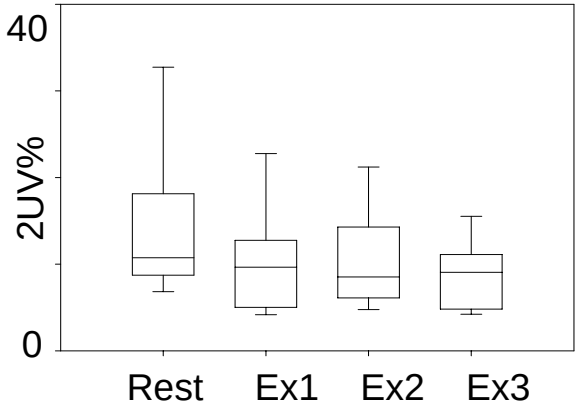


Symbolic Analysis





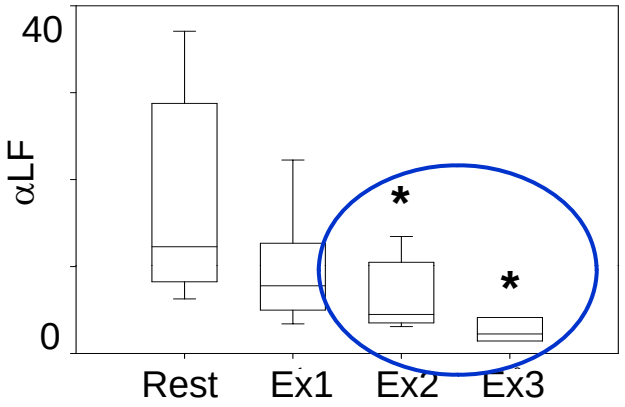


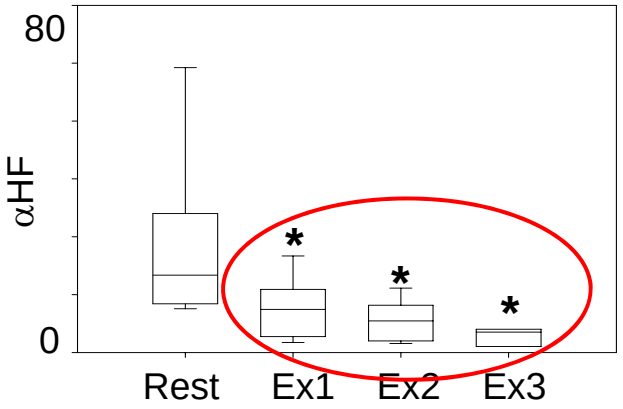


* $p<0.05$ vs rest

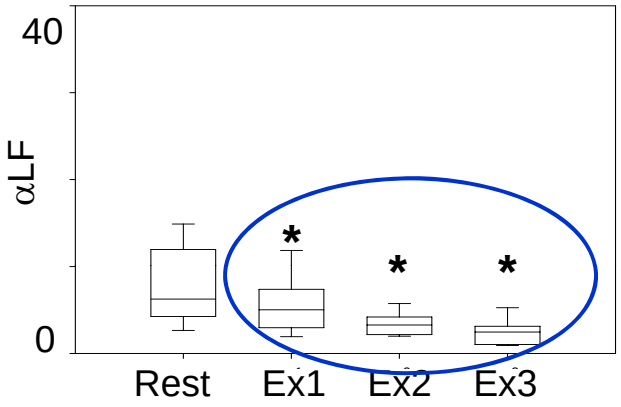
Results – Baroreflex Gain: Exercise protocol

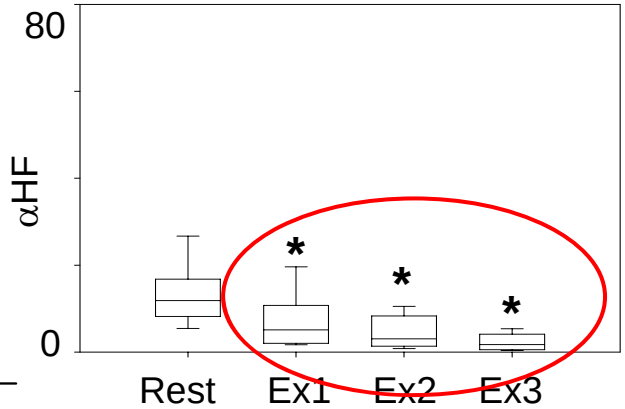
Spectral Analysis





EMD Analysis



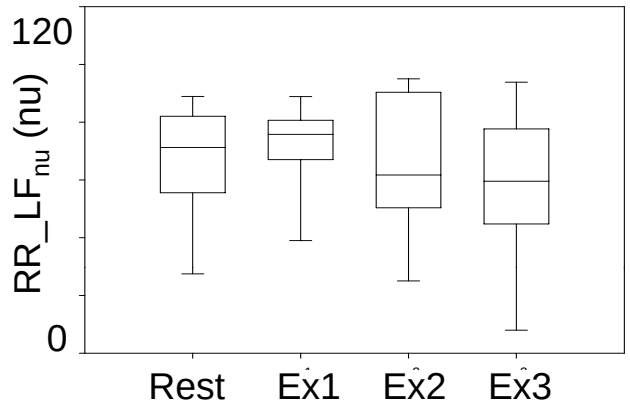


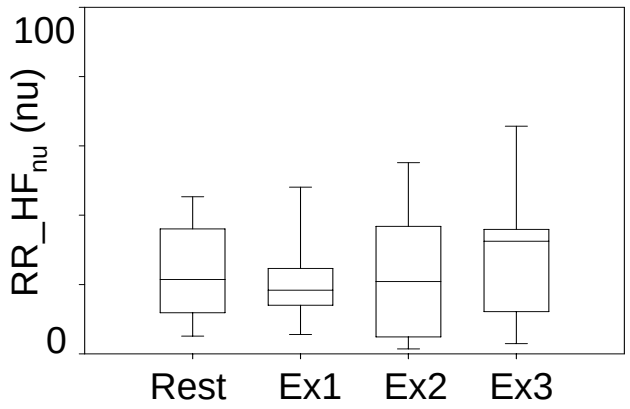
$$\alpha_{LF} = \sqrt{\frac{P_{rr(LF)}}{P_{sap(LF)}}}$$

* p<0.05 vs rest

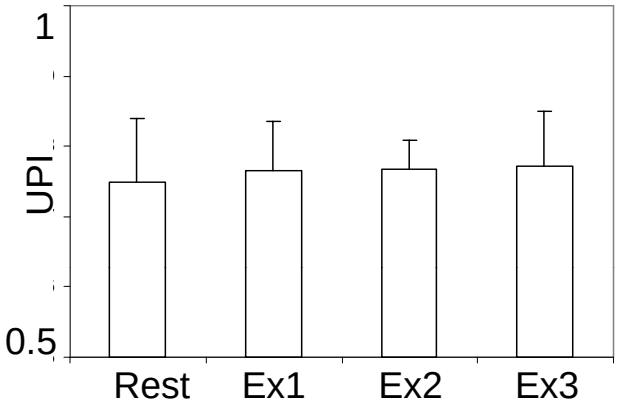
Results - RR: Exercise protocol

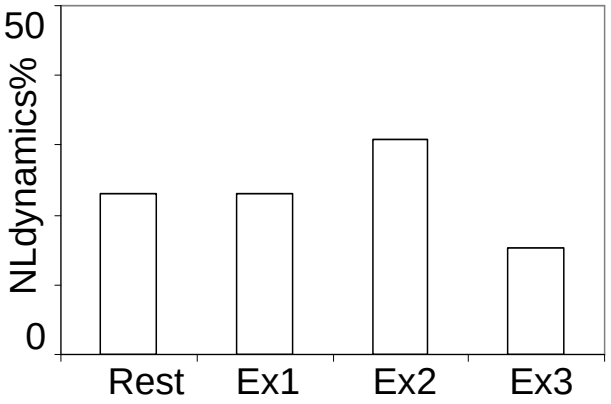
Spectral Analysis





Complexity Analysis





Conclusions & Work in progress

Robotic Assisted treadmill Training

No significant sympathetic activity increases

Improved autonomic control after treatment (! 5 subjects)

? *Correlation between Cardiovascular & Locomotor parameters*

- Gait Analysis
- Motor scores

Work in progress & questions……

Light Cycloergometer Exercise

Baroreflex sequence analysis: Original RR & SAP series VS EMD results

? EMD as a Filter