Heart Rate Variability During Physical Exercise

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Why Heart Rate Variability (HRV)?

- HRV is the existent oscillation of the heart rate
- RR interval = time between two heartbeats

- HRV is an indicator for
  - Fatigue
  - Overtraining
  - Hydration level
  - …
Motivation

EM 2012

Berlin Marathon
How are HRV features changing during one hour of running?

Evaluation with Analysis of Variance (ANOVA)

Reveals significant differences of variables
Study Design

- **295 athletes**
  - 98 female
  - 176 male
  - Age: 43 ± 11 years
  - BMI: 23.1 ± 2.4 kg/m²

One hour outdoor run without distance or speed requirements

* 27 athletes did not answer the questionnaire with respect to gender, age and BMI
Study Design - Equipment

- **Polar RS 800sd**
  Watch, chest strap and shoe sensor

  - Kinematic data (stride frequency, running speed)
  - Physiological data (RR intervals, Heart Rate)
Feature Extraction (1)

- **Time domain features**
  - Average heart rate
  - Square root of the mean squared differences of successive RR intervals:
    \[
    RMSSD = \sqrt{\frac{\sum_{i=1}^{N-1} (RR_{i+1} - RR_i)^2}{N - 1}}
    \]
Feature Extraction (2)

- Frequency domain feature:
  - LF/HF-ratio of normalized power spectral density (PSD)
  - Low frequency (LF) component: 0.04 – 0.15 Hz
  - High frequency (HF) component: 0.15 – 0.40 Hz

![Extract of PSD]
Research Question

- HRV features:
  - Heart Rate
  - RMSSD
  - LF/HF-ratio

How are these three HRV features changing during one hour of running?

Evaluation using Analysis of Variance
Background – ANOVA

• ANOVA = Analysis of Variance

• Aim:
  Determines if significant differences between different groups of variables are existent

• Design: ANOVA with repeated measures

• Procedure:
  • Calculation of F statistic
  • Comparison of F-value to the critical value $F_C$
  • $F_C$ depends on degrees of freedom (df) (Error and Numerator) and significance level $\alpha$
ANOVA with Repeated Measures

- In this study: **Repeated Measures Analysis**
  - Univariate ANOVA with repeated measures
  - Multivariate ANOVA with repeated measures

- Assumptions:
  - Independence of observation
  - Multivariate normality
    → Natural logarithm of RMSSD and LF/HF-ratio
  - Sphericity (Circularity)
    → Only for univariate ANOVA; if violated: Greenhouse & Geisser correction
Results – ANOVA

- **F values**

<table>
<thead>
<tr>
<th></th>
<th>Heart Rate</th>
<th>ln(RMSSD)</th>
<th>ln(LF/HF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>univariate</strong></td>
<td>1452.1</td>
<td>108.6</td>
<td>294.7</td>
</tr>
<tr>
<td><strong>multivariate</strong></td>
<td>796.6</td>
<td>91.8</td>
<td>126.5</td>
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</table>

- **Degrees of Freedom**

<table>
<thead>
<tr>
<th></th>
<th>df Numerator</th>
<th>df Error</th>
<th>Critical F-value</th>
<th>p</th>
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<tbody>
<tr>
<td><strong>univariate</strong></td>
<td>12 (\rightarrow) 1</td>
<td>3528 (\rightarrow) 294</td>
<td>10.83</td>
<td>(&lt;\ 0.001)</td>
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<tr>
<td><strong>multivariate</strong></td>
<td>12</td>
<td>283</td>
<td>2.74</td>
<td>(&lt;\ 0.001)</td>
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Significant differences in the means of Heart Rate, RMSSD and LF/HF-ratio over distinct 5 minute sequences.
Results – Post-Hoc Procedure

- Determination of significant differences in the segments

<table>
<thead>
<tr>
<th>segments</th>
<th>1</th>
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<td>Heart Rate</td>
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<td>ln(LF/HF)</td>
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- No significant differences for all three parameters
  - Starting in different segments
  - Lasting up to the 12th segment
  - For RMSSD: no significant differences after the 2nd segment

→ Indication of start and end of a workout
Summary

• Study
  • 295 volunteers
  • Task: one hour outdoor run
• Three HRV features: Heart Rate, RMSSD, LF/HF-ratio
• Evaluation with ANOVA with repeated measures

How are these three HRV features changing during one hour of running?

• No significant differences for
  Heart Rate between 35 and 60 minutes
  RMSSD between 25 and 60 minutes
  LF/HF-ratio between 30 and 60 minutes
Outlook

- Consideration of additional HRV features and a different segment length

- New methods:
  - Detrended Fluctuation Analysis
  - Dynamic Invariants

- Stride frequency and running speed

- Differences between female and male
Thank you for your attention!

Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology
Quotations