SDNN/RMSSD as a Surrogate for LF/HF: A Revised Investigation.

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Physiological data analysis for educational technologies. SS 2018
1. Stress and psychological state

2. Motivation: SDNN/RMSSD as a surrogate for LF/HF

3. SDNN/RMSSD in detail

4. Pearson correlation coefficient

5. Experiment

6. Results

7. Conclusion

8. Demo: SDNN/RMSSD
Stress and psychological state
Eustress and Distress

1. https://goo.gl/etqkTx
Sympathovagal Balance

Heart Rate Variability

Heart Rate Variability

2.5 seconds of heart beat data

0.859 sec. 70 BPM
0.793 sec. 76 BPM
0.726 sec. 83 BPM

3 https://goo.gl/2JHCPh
Time/Frequency Domain

**Time domain**
- mHR (bpm)
- mRR (ms)
- SDNN
- RMSSD

**Frequency domain**
- LF
- HF
- LF/HF

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4. [https://goo.gl/2JHCPH](https://goo.gl/2JHCPH)
Autonomic Nervous System

**STRESS**
SYMPATHETIC

- PUPILS EXPAND
- FAST & SHALLOW BREATHS
- HEART PUMPS FASTER
- GUT INACTIVE

**CALM**
PARASYMPATHETIC

- PUPILS SHRINK
- SLOW, DEEP BREATHS
- HEART SLOWS
- GUT ACTIVE

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5 https://goo.gl/MSCEwt
Spectral Domain Parameters

1. LF (0.04-0.15 Hz): Low Frequency
   - Shows mixture of SNS and PNS activity
   - Blood pressure regulation
   - Linked to respiration
   - Increase while mental or physical activity

2. HF (0.15-0.4Hz): High Frequency
   - Shows PNS activity
   - Reflects vagal modulation of cardiac activity

3. LF/HF: LF to HF ratio
   - Balance of PNS and SNS activity
   - Normal value 1.5 - 2.0, higher means excessive SNS activity
   - Often described as SVI (sympathovagal index)
Sympathovagal Balance

Motivation: SDNN/RMSSD as a surrogate for LF/HF

- Is SDNN/RMSSD a surrogate for LF/HF?
- What is the quality of this surrogation?

7 https://goo.gl/XJJEp7
Problems with LF/HF

**Procedure**
- Noise reduction
- Interpolation of irregularly time-sampled signal
- Fast-Fourier-Transformation
- Computation of spectral components

**Problems**
- Computationally intensive
- Expertise to apply correctly
- Sensitive to noise

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8 https://goo.gl/o5VGz4
Suggestion: SDNN/RMSSD?

SDNN/RMSSD

- Time Domain Parameters
- Easy to compute
- Stable
- 2 Studies show high correlation to LF/HF\textsuperscript{10, 11}

But: Both studies are not representative
⇒ New Study: A Revised Investigation

\textsuperscript{9} https://goo.gl/CB8RNY
\textsuperscript{11} Sollers J., Buchananet T. al.: Comparison of the ratio of the standard deviation of the r-r interval and the root mean squared successive differences (SD/rMSSD) to the low frequency-to-high frequency (LF/HF) ratio in a patient population and normal healthy controls. Biomedical Sciences Instrumentation, vol. 43, pp. 158–163, 2007
SDNN/RMSSD in detail
**SDNN**: Standard deviation of the RR-interval

\[
\text{MRR} = \bar{I} = \frac{1}{N-1} \sum_{n=2}^{N} I(n),
\]

\[
\text{SDNN} = \sqrt{\frac{1}{N-1} \sum_{n=2}^{N} [I(n) - \bar{I}]^2},
\]

- Correlates with LF in sleep of men\(^\text{12}\)
- SNS and PNS activity contribute to SDNN
- Highly correlated with ULF, VLF and LF\(^\text{13}\)

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SDNN: Example

\[ MRR = \frac{793\text{ms} + 726\text{ms}}{2} \]
\[ = 759.5\text{ms} \]

\[ SDNN = \sqrt{\frac{(33.5\text{ms})^2 + (-33.5\text{ms})^2}{2}} \]
\[ = 33.5\text{ms} \]

\[ \text{MRR} = \bar{I} = \frac{1}{N - 1} \sum_{n=2}^{N} I(n), \]
\[ \text{SDNN} = \sqrt{\frac{1}{N - 1} \sum_{n=2}^{N} [I(n) - \bar{I}]^2}, \]

14 https://goo.gl/2JHCPH
RMSSD: Root mean square of successive heartbeat interval difference

- Correlated with atrial fibrillation and sudden unexplained death in epilepsy
- Correlated with HF power
- Influence of respiration rate is uncertain

\[
MRR = \bar{I} = \frac{1}{N - 1} \sum_{n=2}^{N} I(n)
\]

\[
RMSSD = \sqrt{\frac{1}{N - 2} \sum_{n=3}^{N} [I(n) - I(n - 1)]^2}
\]

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RMSSD: Example

Heart Rate Variability

\[
MRR = \bar{I} = \frac{1}{N - 1} \sum_{n=2}^{N} I(n)
\]

\[
RMSSD = \sqrt{\frac{1}{N - 2} \sum_{n=3}^{N} [I(n) - I(n - 1)]^2}
\]

\[
MRR = \frac{793\text{ms} + 726\text{ms}}{2}
\]

\[
= 759.5\text{ms}
\]

\[
RMSSD = \sqrt{\frac{(793\text{ms} - 726\text{ms})^2}{1}}
\]

\[
= 67\text{ms}
\]

\[17\text{ https://goo.gl/2JHCPH}\]
Pearson correlation coefficient
We want to know:

- Can LF/HF be surrogated by SDNN/RMSSD?
- What quality does this surrogation have?

**Solution: Pearson correlation coefficient** \( r \)

- Measure of the linear correlation between two variables \( X \) and \( Y \)
- Values from -1 to 1, \( r \in [-1, 1] \)
- \( r \) close to 1 → positive correlation
- \( r \) close to -1 → negative correlation
- \( r \) close to 0 → no correlation
- \( r^2 \) used as a coefficient of determination of the regression model
Pearson correlation coefficient - Examples

\[ r = \frac{S_{XY}}{\sqrt{S_{XX}S_{YY}}}, \quad r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \]

18 https://goo.gl/u5o6eQ
Correlation of LF/HF to SDNN/RMSSD

Paper 1: Sollers, Buchanan, Mowrer et al. ¹⁹

- Group of prefrontal cortex patients
- Correlation coefficient of 0.94

Paper 2: Balocchi, Cantini, Maurizio et al. ²⁰

- Resting supine state (70°)
- Correlation coefficient of 0.90

Problem: Only two special cases

²⁰ Sollers J., Buchananet T. al.: Comparison of the ratio of the standard deviation of the r-r interval and the root mean squared successive differences (SD/rMSSD) to the low frequency-to-high frequency (LF/HF) ratio in a patient population and normal healthy controls. Biomedical Sciences Instrumentation, vol. 43, pp. 158–163, 2007
Experiment
Setup

New experiment by Wang H. and Huang S.  

- 32 male, healthy adults
- 21-25 years
- On chair in quiet room
- Closed eyes
- 6 identical experiments in 6 weeks
- 20 minutes per experiment

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22 https://goo.gl/m42Kvi
Data Analysis

Two different time windows for data analysis

- 3- and 5-minute intervals
- 2.5 min to 17.5 min for 5-min intervals
- 1 min to 19 min for 3-min intervals
- Head and tail were cut off for stability
Results
One single subject in the first experiment, 3-min interval

<table>
<thead>
<tr>
<th>Week 1</th>
<th>01–04</th>
<th>04–07</th>
<th>07–10</th>
<th>10–13</th>
<th>13–16</th>
<th>16–19</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>78</td>
<td>75</td>
<td>74</td>
<td>74</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td>MR</td>
<td>772</td>
<td>802</td>
<td>814</td>
<td>807</td>
<td>768</td>
<td>761</td>
</tr>
<tr>
<td>SD</td>
<td>99</td>
<td>79</td>
<td>92</td>
<td>107</td>
<td>108</td>
<td>105</td>
</tr>
<tr>
<td>RM</td>
<td>46</td>
<td>37</td>
<td>46</td>
<td>47</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>S/R</td>
<td>2.2</td>
<td>2.1</td>
<td>2.0</td>
<td>2.3</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>LF</td>
<td>1731.2</td>
<td>1383.5</td>
<td>2087.4</td>
<td>1991.2</td>
<td>2335.9</td>
<td>3131.6</td>
</tr>
<tr>
<td>HF</td>
<td>229.1</td>
<td>193.3</td>
<td>317.0</td>
<td>436.9</td>
<td>409.7</td>
<td>511.8</td>
</tr>
<tr>
<td>L/H</td>
<td>7.6</td>
<td>7.2</td>
<td>6.6</td>
<td>4.6</td>
<td>5.7</td>
<td>6.1</td>
</tr>
</tbody>
</table>
Correlation coefficient

5th experiment 7.5–12.5 min

$$\text{SDNN/RMSSD} = 1.593 + 0.0941 \text{ LF/HF}$$

![Graph showing correlation between SDNN/RMSSD and LF/HF]

- **Regression**: R-Sq 49.9%
- **95% CI**: R-Sq (adj) 48.3%
- **S**: 0.414617
Correlation trend - 5 min intervals

<table>
<thead>
<tr>
<th></th>
<th>2.5–7.5 min</th>
<th>7.5–12.5 min</th>
<th>12.5–17.5 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>0.6</td>
<td>0.4</td>
<td>0.59</td>
</tr>
<tr>
<td>Week 2</td>
<td>0.65</td>
<td>0.56</td>
<td>0.47</td>
</tr>
<tr>
<td>Week 3</td>
<td>0.54</td>
<td>0.5</td>
<td>0.44</td>
</tr>
<tr>
<td>Week 4</td>
<td>0.49</td>
<td>0.48</td>
<td>0.39</td>
</tr>
<tr>
<td>Week 5</td>
<td>0.7</td>
<td>0.68</td>
<td>0.5</td>
</tr>
<tr>
<td>Week 6</td>
<td>0.52</td>
<td>0.6</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Correlation trend - 3 min intervals

<table>
<thead>
<tr>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.57</td>
<td>0.58</td>
<td>0.41</td>
<td>0.45</td>
<td>0.54</td>
<td>0.51</td>
</tr>
<tr>
<td>0.56</td>
<td>0.61</td>
<td>0.65</td>
<td>0.49</td>
<td>0.7</td>
<td>0.53</td>
</tr>
<tr>
<td>0.38</td>
<td>0.6</td>
<td>0.42</td>
<td>0.6</td>
<td>0.65</td>
<td>0.61</td>
</tr>
<tr>
<td>0.54</td>
<td>0.57</td>
<td>0.42</td>
<td>0.66</td>
<td>0.46</td>
<td>0.67</td>
</tr>
<tr>
<td>0.59</td>
<td>0.56</td>
<td>0.47</td>
<td>0.58</td>
<td>0.61</td>
<td>0.74</td>
</tr>
<tr>
<td>0.29</td>
<td>0.53</td>
<td>0.48</td>
<td>0.33</td>
<td>0.48</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Distribution of 5 min, 3 min

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Stdev</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>0.5471</td>
<td>0.1021</td>
<td>18</td>
</tr>
<tr>
<td>3 min</td>
<td>0.5367</td>
<td>0.1092</td>
<td>36</td>
</tr>
</tbody>
</table>
Conclusion
Conclusion

Positive

- SDNN/RMSSD was a proper surrogate for LF/HF in 2 special cases.
- Stability of RMSSD and HF in various epochs

Negative

- The mean in a further experiment was under 0.6
- Correlation between SDNN and LF remain to be discussed
- The robustness of the surrogate aspect needs more confirmation

→ At the moment SDNN/RMSSD is not a reliable surrogate for LF/HF
Future work

- More participants, more data
- Different environments
- Varied participant groups
- Increase reliability
- Different time intervals

https://goo.gl/gGibjv
Demo: SDNN/RMSSD
Formulas

Standard deviation of RR intervals:

$$SDRR = \sqrt{\frac{\sum_{i=1}^{N}(RR_i - mRR)^2}{N-1}}$$

Root mean square of successive interval differences:

$$RMSSD = \sqrt{\frac{\sum_{i=1}^{N-1}(RR_{i+1} - RR_i)^2}{N-1}}$$

SDRR to RMSSD ratio:

$$\frac{SDRR}{RMSSD} = \frac{SDRR}{RMSSD}$$
```python
def featureCalculation_RMSSD(segment):
    RR = featureCalculation_RR(segment)
    tmp = [(RR[i+1]-RR[i])**2 for i in range(len(RR)-1)]
    return np.sqrt(np.mean(tmp)) if tmp else 0

def featureCalculation_SDRR(segment):
    """
    Takes a Segment of hrValues
    Transforms them to rrValues
    Calculates the standard deviation
    """
    return np.std(featureCalculation_RR(segment))

def featureCalculation_SDRR_RMSSD(segment):
    return featureCalculation_SDRR(segment)/featureCalculation_RMSSD(segment)
```
Cardio - mHR

80 minutes cardio training

meanHR to datetime at 2018-05-16

meanHR

Sleep  Waking Up  Cardio  Relaxing

time line [hh:mm]
Cardio - RMSSD and SDRR

**RMSSD to datetime at 2018-05-16**

- Sleep
- Waking Up
- Cardio
- Relaxing

**SDRR to datetime at 2018-05-16**

- Sleep
- Waking Up
- Cardio
- Relaxing
Cardio - Stress and RMSSD/SDRR

SDRR-RMSSD ratio to datetime at 2018-05-16

Sleep  Waking Up  Cardio  Relaxing

SDRR/RMSSD [%]

Time line (hh:mm)

05:00  06:00  07:00  08:00  09:00  10:00
Working with positive feeling and good performance
Working - RMSSD and SDRR

RMSSD to datetime at 2018-05-18

SDRR to datetime at 2018-05-18
SDRR-RMSSD ratio to datetime at 2018-05-18

- MVV
- ORG
- Work
- Lunch

time line [hh:mm]
Writing a stressful exam under pressure

![Graph showing meanHR over time with different activities labeled: MVV, Exam, Walking.](image)
Exam - RMSSD and SDRR

RMSSD to datetime at 2018-04-20

SDRR to datetime at 2018-04-20
Exam - Stress and RMSSD/SDRR