Heart Rate Variability (HRV) of two short-term photoplethysmogram (PPG)

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Abstract

Heart rate variability (HRV) is often analyzed using short-term studies: 5-min and 2-min heart rate datasets. The correlation between the two data segments in HRV analysis has not been well understood. This paper reports a statistical comparison of the results of HRV spectral analysis for the 5-minute versus 2-minute short-term studies using photoplethysmogram (PPG). Twenty repeat measurements were performed to obtain the comparison data, the power spectral density (PSD) was analyzed for data segments and divided into three frequency components: Ln_VLF, Ln_LF, and Ln_HF. For statistical comparison, we used Pearson’s correlation coefficient (ρ) and a paired t-test. The ρ was 0.3827 (p = 0.0958) for Ln_VLF, 0.6518 (p = 0.0018) for Ln_LF, 0.9250 (p < 0.0001) for Ln_HF, 0.8807 (p < 0.0001) for the R ratio (Ln_LF/Ln_HF), and 0.9592 (p < 0.0001) for the standard deviation (SD). In a paired t-test for the R ratio, the t-statistic, SD, and two-tailed probability were 0.602, 0.07797, and P=0.5541, respectively. Our findings suggest that 2-minute recordings may be appropriate for screening the HRV parameters that reflect the autonomic nervous system (ANS) function and that the 2-minute HRV remains useful, although there is some difference between the HRV parameters of the 2-minute and 5-min HRV.

Keywords: Autonomic nervous system, heart rate variability, Photoplethysmogram

1. Introduction

Heart rate variability (HRV) is largely under the control of the autonomic nervous system (ANS), which consists of the parasympathetic nerve that decreases heart rate and the sympathetic nerve that increases heart rate [1-3]. The ANS is comprised of many different components. Some portions help us think, control our emotions and manage the movement and balance of our body. Control of the ANS arises from the hypothalamus and the spinal cord and essentially coordinates the function of every organ in the human body. Research has demonstrated for many years that ANS balance between the parasympathetic nerve and sympathetic nerve is required for the maintenance of overall health. ANS imbalance tends to destabilize a patient’s response to therapy and disease, and over time leads to overt symptoms.

In a 5-minute period, heart rate rhythm is determined by changes in respiration, baroreceptor, chemoreceptor and autonomic neural activity, while in a 24-hour period, body temperature, metabolic rate, hormones, and sleep cycles also contribute to HRV [4-7]. However, a shorter measurement time provides more practical advantages with easy application in a clinical setting and can be a quick monitoring method in personal healthcare [8-11]. Heart rate variability analysis over shorter periods may be very useful for monitoring dynamic changes in autonomic nervous system activity where steady-state conditions are not maintained [10].

For this reason, several studies have demonstrated that the combination of the 5-minute HRV parameters is a strong indicator of clinical significance in the normal population and patients [12-14]. Although it is not well understood whether a 5-minute segment is representative enough for assessment of the ANS function, we agree that the 5-min HRV spectral analysis has good reproducibility [15].

In this study we have focused on evaluating the accuracy and reproducibility of measuring HRV for 2 minutes. Heart rate rhythm fluctuation for a 2-minute period might demonstrate slower sympathetic response time, with a delay of up to 5 seconds before the heart rate is affected, including faster parasympathetic response time. To test this assumption, we used the Discrete Fourier Transform (DFT) to evaluate the correlation between spectral bands produced when measuring HRV for simultaneous 2-minute and 5-minute periods.
2. Materials and Methods

2.1 Subject data

Four healthy volunteers (20-49 years old) participated in this study. All subjects submitted written informed consent before participating in this investigation. Five repeat measurements for each participant were carried out to obtain 20 sets of data in total. There are many factors that may influence the HRV, such as body position, activity level prior to recording, medication, and breathing conditions. For that reason, we took special precautions to maintain similar conditions in a sitting body position to minimize the difference between the SDs of the 5-minute and 2-minute datasets.

Data were simultaneously obtained by PPG measurement using two instruments: CANOPY9 RSA (IEMBIO Co. Ltd., Chuncheon-si, Korea). A PPG fingertip sensor has an infrared diode (910 nm wavelength) and a photodiode for sensing the blood volume changes. The PPG signals were sampled to 1000 samples s\(^{-1}\) and heart rate was calculated in milliseconds. The PSD was analyzed, and the SD was calculated by the instrument. The recordings were digitized at 1000 samples per second per channel with 12-bit resolution over a 100mV range. Figure 1 shows how to measure 5-minute and 2-minute data simultaneously.

![Figure 1](image.png)

**Figure 1.** The experimental setup for the acquisition of heart rate tachogram using two instruments. Two short-term recordings were simultaneously obtained using a fingertip PPG sensor: 2-minute and 5-minute.

2.2 Spectral analysis

The main advantages of power spectral density (PSD) analysis over the time domain measures is that it supplies information on how the power is distributed (the variance) as a function of frequency. The spectral components (VLF, LF, and HF) of the HRV which represent the different branches of the autonomic system were calculated using Fast Fourier Transform (FFT).

A DFT was used to determine three spectral energies in each 5-minute and 2-minute dataset. For the 2-minute segment, the frequency limits correspond to very low frequency (VLF 0.0083 to 0.04 Hz), low frequency (LF 0.04 to 0.15 Hz), and high frequency (HF 0.15 to 0.4 Hz). However, in the 5-minute segment, VLF ranges from 0.0033 Hz to 0.04 Hz, and the other limits are the same. The frequency resolution is 0.0033 Hz for a 5-minute period and 0.0083 Hz for a 2-minute period. It was calculated by dividing 1000 data points by the measurement time in milliseconds.

The mathematical equations for calculating the PSD for each frequency range were employed in the following. A set X of dimensional vectors represents the PSD corresponding to frequency, k.
The PSD is reported in absolute values, expressed as milliseconds squared, and converted into a natural logarithm: Ln_VLF, Ln_LF, and Ln_HF. Ln_LF is divided by Ln_HF to obtain the R ratio, representing the ratio of sympathetic nerve activity to parasympathetic nerve activity. The HF range reflects the fast changes in the beat-to-beat variability due to parasympathetic stimulation, whereas the VLF is thought to reflect mostly sympathetic stimulation. The LF region represents a mixture of both sympathetic and parasympathetic stimulation of the heart.

2.3 Statistical analysis

We calculated the mean, concordance correlation coefficient (ρC), and Pearson’s correlation coefficient (ρb) to describe the relationship between 2-min and 5-min HRV analyses. The ρC was calculated to investigate the statistical significance of the differences in data between the two short-term recordings. The ρC contains a measurement of precision (ρb) and accuracy (Cb): ρC = ρb * Cb, where ρb measures how far each observation deviates from the best-fit line and Cb is a bias correction factor that measures how far the best-fit line deviates from the 45 degree line through the origin [16].

Moreover, we calculated the mean, variance, SD, and median using a t-test for the R ratio comparison data. The paired t-test is applied to test the null hypothesis that the average of the difference between R ratios is zero. It is used to compare the levels of R ratios between matched pairs of two measurements. The p-value is two-tailed because the mean difference may be either negative or positive. The paired t-test displays the summary statistics with a 95% confidence interval (CI) for the mean.

To explore the relationship between changes of HRV parameters for each measurement, we used the repeated measures ANOVA. If the p-value is low (p < 0.05), it can be concluded that there is significant difference between the different measurements. We used a graphical presentation to visually confirm the data difference. The statistical analysis was performed using the MedCalc program (MedCalc software, Belgium).

3. Results

We investigated the influence of two short-term studies on HRV parameters. Figure 2 shows that 2-minute and 5-minute datasets were associated with no significant changes of all frequency domain parameters studied except for Ln_VLF: Ln_VLF (p = 0.0035), Ln_LF (p = 0.1294), Ln_HF (p = 0.0848), and R ratio (ANOVA, p = 0.5541). Ln_VLF (4.5340) for the 2-minute period was an average of 11% less than the Ln_VLF (5.1110) for the 5-minute period.
The correlations between frequency domain measures of HRV, including SD in the time domain, were presented in Table 1. An extremely high correlation was found between the Ln_HF (ρ_C = 0.9072 and ρ_b = 0.9250) of the 2-minute and 5-minute periods for the frequency domain analysis. Ln_LF (ρ_C = 0.6198 and ρ_b = 0.6518) was correlated with moderate strength, but Ln_VLF (ρ_C = 0.2737 and ρ_b = 0.3827) correlated with low strength. SD in the time domain showed the highest correlation (ρ_C = 0.9570 and ρ_b = 0.9592). The R ratio, corresponding to the ratio of sympathetic activity to parasympathetic activity, was well correlated (ρ_C = 0.8764 and ρ_b = 0.8764).

Figure 3 shows a graph of the deviation by the HRV parameters from the 45 degree line through the origin. In Table 2, the correlation between the R ratios determined by the paired t-test was presented for 2-minute and 5-minute periods as variance (0.02681 and 0.02320), SD (0.1637 and 0.1523), lowest value (0.69 and 0.76), highest value (1.46 and 1.33), and median (0.95 and 0.96, 2-min and 5-min). R ratio was reported as a mean difference (0.01050) with a 95% CI of -0.02599 to 0.04699, t-statistic (0.602), and two-tailed probability (P=0.5541). Because the calculated P-value is higher than 0.05, the mean difference between R ratios are almost zero. High t-statistic showed that the data points were serially correlated.
### Table 1. Statistical results of HRV parameters by concordance correlation coefficient. \( \rho_C \) is concordance correlation coefficient with a 95% confidence interval, \( \rho_b \) Pearson’s correlation coefficient, and \( C_b \) bias correction factor.

<table>
<thead>
<tr>
<th>Pairs</th>
<th>Ln_VLF</th>
<th>Ln_LF</th>
<th>Ln_HF</th>
<th>R ratio</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_C )</td>
<td>0.2737</td>
<td>0.6198</td>
<td>0.9072</td>
<td>0.8764</td>
<td>0.9570</td>
</tr>
<tr>
<td>95% CI</td>
<td>-0.05458 to 0.5486</td>
<td>0.2768 to 0.8227</td>
<td>0.7898 to 0.9605</td>
<td>0.7183 to 0.9484</td>
<td>0.8976 to 0.9823</td>
</tr>
<tr>
<td>( \rho_b )</td>
<td>0.3827</td>
<td>0.6518</td>
<td>0.925</td>
<td>0.8807</td>
<td>0.9592</td>
</tr>
<tr>
<td>(p = 0.00958)</td>
<td>(p = 0.0018)</td>
<td>(p &lt; 0.0001)</td>
<td>(p &lt; 0.0001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( C_b )</td>
<td>0.7151</td>
<td>0.9509</td>
<td>0.9808</td>
<td>0.9951</td>
<td>0.9977</td>
</tr>
</tbody>
</table>

### Table 2. Summary statistics of the R ratios using paired t-tests.

<table>
<thead>
<tr>
<th>R ratio</th>
<th>R ratio 2-min</th>
<th>R ratio 5-min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic mean</td>
<td>0.9680</td>
<td>0.9785</td>
</tr>
<tr>
<td>95% CI for the mean</td>
<td>0.8914 to 1.0446</td>
<td>0.9072 to 1.0498</td>
</tr>
<tr>
<td>Variance</td>
<td>0.02681</td>
<td>0.02320</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.1637</td>
<td>0.1523</td>
</tr>
<tr>
<td>SD of the mean</td>
<td>0.03661</td>
<td>0.03406</td>
</tr>
<tr>
<td>Lowest value</td>
<td>0.69</td>
<td>0.76</td>
</tr>
<tr>
<td>Highest value</td>
<td>1.46</td>
<td>1.33</td>
</tr>
<tr>
<td>Median</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>95% CI for the median</td>
<td>0.8834 to 0.9800</td>
<td>0.8717 to 1.0366</td>
</tr>
</tbody>
</table>

### Paired t-test

| Mean difference | 0.01050 |
| SD of differences | 0.07797 |
| 95% CI for the mean | -0.02599 to 0.04699 |
| Test statistic t | 0.602 |
| Two-tailed probability | P=0.5541 |
Figure 3. HRV parameters that deviated from the 45 degree line through the origin are compared using the scatter diagram. Their values are expressed as natural logarithm: Ln_VLF (VLF_5m, VLF_2m), Ln_LF (LF_5m, LF_2m), and Ln_HF (HF_5m, HF_2m). The R ratio is a dimensionless unit.

4. Discussion

We found that all HRV parameters, except for Ln_VLF, were highly correlated between the 2-minute and 5-minute data segments and that there was no significant difference between R ratios, reflecting sympathovagal balance. Ln_HF, the parameter characterizing parasympathetic tone, was best correlated and Ln_VLF was poorly correlated, even though the SD was extremely associated. The reason is because low frequency resolution (0.0083 Hz) for 2 minutes could not provide spectra below 0.0033 Hz to calculate VLF (0.0033 to 0.04 Hz) with higher frequency resolution (0.0033 Hz) for 5-minutes.

A resolution reduced by 2.5 times caused the reduction of values of Ln_VLF for the 2-minute periods, resulting in poor correlation. This finding may also limit the ability of a 2-minute period to reflect the overall autonomic activity because sympathetic activity that reflects Ln_VLF is the primary contributing factor. Accelerations and decelerations of heart rate will not influence the correlation between HRV parameters. As a result of the correlations established in the present study, we conclude that it is reasonable to consider Ln_LF and Ln_HF, analyzed for 2 minutes, as alternatives to the standard 5-minute HRV parameters, with the exception of Ln_VLF.

However, after application of an appropriate correction factor to Ln_VLF, we suggest that HRV parameters obtained using 2-minute HRV recording periods could be extrapolated to those using 5-minute HRV recording periods. Correction factor was used to improve the correlation coefficient between Ln_VLFS. It is concluded that the 2-minute heart rate variability analysis might be more useful in the case of rapid changing body conditions such as drug administration, or the start or end of exercise than 5-minute analysis. This study provided methods of HRV analysis searching for indices that could be applied to the 2-minute short time HRV analysis, but in future all indices both in time- and frequency-domains would be tested with various short segments of archived data.
5. References