Comparison of Polar V800 with Healink R211B for the Purpose of Analyzing Heart Rate Variability

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Abstract. Heart rate variability (HRV) is generally accepted as the best method to evaluate the function of the human autonomic nervous system. This paper compares the differences between the Polar V800 and the Healink R211B in the application of HRV analysis. Twenty-nine healthy college students participated in the study. The data were recorded simultaneously by both devices from all the subjects in a resting state. After being processed, the RR interval (RRI) data for 26 of the cases from the two devices were imported into the Kubios HRV software and were approximately consistent in regards to the HRV parameters. There was no significant difference ($r > 0.99, p > 0.05$) between the two devices except for the $\alpha 1$ parameter ($p = 0.021$). For the other 3 cases, the Polar V800 RRI could not be corrected due to partially missing data. Therefore, the HRV analysis and comparison were not conducted. The results indicate that the Polar V800 and the Healink R211B combined with Kubios HRV software can be used for HRV analysis in the time domain, frequency domain and for partial nonlinear parameter analysis, except in cases where data were missed by the Polar V800. However, it should be noted that approximately 10% of the samples from the Polar V800 have more RRI values missing so the entire sample data could not be used for HRV analysis.

1. Introduction
Heart rate variability (HRV) refers to the phenomenon that there are differences in the time between successive heartbeats. It is recognized as the best method to evaluate the function of the human autonomic nervous system by both the European Society of Cardiology (ESC) and the North American Society of Pacing and Electrophysiology (NASPE) [1]. In the past decade, the rapid development of electronic and computer technology has greatly promoted the research and application of HRV analysis in medicine. Existing studies have shown that most HRV parameters decrease with age [2, 3], with increasing physical activity [4], and with diseases such as diabetes, hypertension, cancer, etc. [5].

HRV is usually measured by analyzing the time series of RR intervals (RRI) in electrocardiograph (ECG) signals, and this is currently the gold standard for HRV analysis. Currently, ECG data collection is relatively easy, and it can be achieved outside of hospitals with portable ECG devices or wearable ECG sensors. Therefore, some health management agencies have carried out services about health assessment and early disease warnings based on HRV analysis. Among the commercial heart rate and ECG devices, Polar’s heart rate monitor (HRM; Polar Electro Oy, Kempele, Finland) is
favored by users due to its convenience and strong anti-jamming capability. Many researchers have combined RR data documented by Polar HRM with the Kubios HRV software for HRV analysis in the fields of clinical [9-11], psychological [12, 13], sports and physiological [14] research. Therefore, are the RRI data recorded by Polar HRM accurate? Various studies have verified the S810, RS800, V800 and other series belonging to Polar. Some results show that the RRI data recorded by Polar HRM in the quiet state are almost consistent with the RRI data obtained by an ECG device [15, 16]. Some studies also indicate that the traditional ECG device should be used as far as possible when conditions permit [17]. We also found some problems in HRV analysis and research when we used a Polar V800 (Polar Electro Oy, Kempele, Finland) and a Healink R211B Micro-ECG recorder (Healink Ltd., Bengbu, China). The main purpose of this paper is to compare the effects of HRV analysis between the two devices in the resting state.

2. Methods

2.1. Subjects
The subjects were 29 healthy college students from Bengbu Medical College, including 17 boys and 12 girls, age 20.6±1.0yr, height 1.69±0.06m, weight 60.9±9.5kg, and BMI 20.8±3.1kg/m². All subjects had no history of heart disease or hypertension and were informed of the purpose and the details of the experiment before it started. This study was approved by the Ethics Committee of Bengbu Medical College.

2.2. Instruments
An H10 chest strap (ID: 27414E2A; Polar Electro Oy, Kempele, Finland) and a Healink R211B Micro-ECG recorder (Healink Ltd., Bengbu, China) were selected for the experiment, and a comparison was made between the two devices. The H10 chest strap needs to cooperate with the Polar V800 to record RRI. The firmware version of the Polar V800 is 1.11.49. The firmware version of the Micro-ECG recorder is 2.3.0, the signal bandwidth is 0.6-40Hz, and sampling rate is 400Hz.

2.3. Experimental Procedure
Subjects were in a sedentary state, and the RRI data were recorded by the Polar V800 and H10. At the same time, the ECG data were collected by a Micro-ECG recorder. The test time was 6min. Disposable gel Ag/AgCl ECG electrodes were used for the ECG data collection. The leading mode was V5.

2.4. Data Processing and Analysis
The entire data processing flow is shown in Fig. 1.

The RRI data recorded by the Polar V800 were synchronized to the network server via Bluetooth and exported by logging into the official Polar website. The ECG data recorded by Healink R211B were transmitted to the computer through a USB data cable, and then the RRI data were calculated by a MATLAB (Mathworks, Natick, MA, USA) program that uses the Hilbert transform [18].

Five min of data were selected from 6 min of the Polar V800 data and the other 5 min of data at corresponding time points were extracted manually from the RRI data from the Healink R211B ECG.
In the corresponding process, it was found that there were different types of errors between the partial RRI data obtained by the Polar and the Healink. Gamelin et al. proposed 5 types of errors for error classification, which are T1 to T5 [19]. On this basis, Giles et al. added T6 type and divided it into T6-a and T6-b [16]. This paper classifies and corrects these 6 error types.

First, the RRI data were imported into the Kubios HRV (Version 2.2; University of Eastern Finland, Kubios, Finland) to analyze the HRV parameters. The parameters to be compared are as follows:

- **Time Domain Parameters of HRV**: the standard deviation of the normal RRI (SDNN), the root mean square for successive RRI differences (RMSSD), the number of successive normal RRIIs greater than 50ms (NN50), and the percentage of NN50 in the total number of RRI (pNN50).

- **Frequency Domain Parameters of HRV**: total power (TP) (0–0.4Hz), low frequency (LF) (0.04–0.15Hz), high frequency (HF), normal low frequency (LF norm), normal high frequency (HF norm) and the ratio of low to high frequency power (LF/HF).

- **Nonlinear parameters of HRV**: Poincaré plots of SD1 and SD2, approximate entropy (ApEn), sample entropy (SampEn), detrended fluctuation analysis (DFA), short-term fractal scale index ($\alpha_1$) ($4 \leq n \leq 16$) and long-term fractal scale index ($\alpha_2$).

### 2.5. Statistical Analysis

First, variance analysis and paired t-tests were used for all variables.

Next, a statistical analysis of intergroup data was performed using Pearson linear correlation analysis and the Bland-Altman method [20].

The Pearson correlation coefficient $r$ is a parameter that measures the degree of correlation between two sets of random variables $x$ and $y$. Its calculation formula is

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$  \hspace{1cm} (1)

In the above formula, $n$ is sample number. The value of $r$ is between -1 and +1. If $r$ is greater than 0, it means that the two variables are positively correlated; if $r$ is less than 0, it means that the two variables are negatively correlated. The larger the absolute value of $r$ is, the stronger is the correlation. If $r$ is equal to 0, it means that the two variables are not linearly related.

The Bland-Altman method is a method for assessing consistency problems by performing random effects analysis on the difference between two measurements; thus, it is a combination of qualitative and quantitative methods. A Bland-Altman scatter plot can qualitatively observe the differences between two measurements. The X-axis is the mean value of the two measurements, and the Y-axis is the difference in value between the two measurements. The formula is expressed as

$$S(X, Y) = \left(\frac{x + y}{2}, x - y\right)$$  \hspace{1cm} (2)

A 95% acceptable consistency limit of the two sets of data is calculated by using the mean value of the two differences ± 1.96 standard deviations, expressed as

$$\text{LoA}(95\%) = \bar{d} \pm 1.96s$$  \hspace{1cm} (3)

In the formula, $\bar{d}$ and $s$ are the mean value and standard deviation of the difference between $x$ and $y$, respectively.
3. Results
A total of 29 cases of data were measured in the experiment, and 16 cases of Polar data (55%) could be aligned with the Healink data without corrections; these data were defined as N type. Thirteen cases of Polar data (45%) showed four errors, which were T4, T5, T6-a and T6-b error types. T1, T2 and T3 error types were not found. The data classification is shown in Tab. 1.

| Type | Correction Method | Number of Cases (29) |
|------|-------------------|----------------------|
| N    | Without correction| 16                   |
| T4   | Split a point into two points | 1           |
| T5   | Combine two points into one point | 1           |
| T6-a | Missed many consecutive checks and cannot be corrected | 3           |
| T6-b | Take the average of two adjacent points (No more than 3 consecutive lost) | 8           |

T4 and T5 type errors each have 1 case, as shown in Fig. 2(a) and Fig. 2(b). These types of error data can be corrected by dividing a point into two points or combining two points into one point. As shown in Fig. 2(c), there are 3 cases of T6-a type data. Because the RRI data are missing too much information, a 0 is inserted into the figure to indicate the missing point rather than to correct it. Eight cases of T6-b type errors, missing one or several RRI datapoints, are found by comparing them with the Healink data. The original and corrected Polar data are shown in Fig. 2(d).

![Figure 2. Error types of the Polar data.](image-url)
There are 6411 pairs of Polar and Healink data in 16 cases, and the two groups of values can be aligned without corrections. Among Polar's four types of data errors, T4 and T5 errors are easiest to detect, with a total of 7 points, which can be corrected without reference to Healink. After correction, there are 7243 pairs of values in total, together with 16 normal datasets. There is a strong correlation between the two groups ($r = 0.9999$) ($p < 0.001$), with a mean value difference of 1.1 ms, and the range of 95% LoA is (-1.5, 3.8) ms. The results are shown in Fig. 3.

![Graph (a) Relationship between Polar and Healink](image1)

![Graph (b) Bland–Altman plot](image2)

**Figure 3.** Corrections between Polar and Healink data.

In the process of using Polar, it is thought that T6-b type errors cannot be corrected if there is no Healink data to use as a reference. Therefore, HRV analysis was performed on a total of 26 datasets of N, T4, T5 and T6-b (uncorrected) types. For Polar and Healink data, the results of time domain parameters, frequency domain parameters and various nonlinear parameters are shown in Tab. 2.

| HRV          | Polar       | Healink     | $t/Z$ | $p$    | Correlation | Bias    | LoA            |
|--------------|-------------|-------------|-------|--------|-------------|---------|----------------|
| Mean RR      | 754.5±112.2 | 754.0±112.0 | -1.335| 0.182  | 1.0000      | -1.24   | -1.75 to -0.70 |
| SDNN         | 45.1±15.9   | 45.0±15.8   | 1.056 | 0.301  | 0.9999      | -0.12   | -0.41 to 0.16  |
| RMSSD        | 31.5±13.9   | 31.7±13.9   | -1.675| 0.094  | 0.9999      | -0.14   | -0.55 to 0.27  |
| NN50         | 46.8±44.7   | 47.1±45.0   | -0.826| 0.417  | 0.9999      | -0.38   | -3.48 to 2.71  |
| pNN50        | 12.8±13.7   | 12.9±13.8   | -0.716| 0.481  | 0.9996      | -0.13   | -0.97 to 0.70  |
| VLF          | 879.1±1263.2| 874.8±1256.6| -1.200| 0.230  | 1.0000      | -3.19   | -15.60 to 9.21 |
| LF           | 680.9±785.7 | 682.9±782.4 | -1.446| 0.148  | 1.0000      | -4.08   | -20.10 to 11.94|
| HF           | 515.7±460.9 | 512.8±460.4 | 1.675 | 0.106  | 0.9999      | -4.04   | -17.34 to 9.26 |
| TP           | 2062.2±1902.7| 2071±1902.2 | -1.744| 0.081  | 1.0000      | -11.35  | -39.07 to 16.38|
| LFnu         | 55.9±15.1   | 56.0±15.0   | -0.860| 0.398  | 0.9994      | 0.23    | -0.82 to 1.28  |
| HFnu         | 44.1±15.1   | 43.9±15.0   | 0.840 | 0.409  | 0.9994      | -0.22   | -1.28 to 0.85  |
| LF/HF        | 1.6±1.2     | 1.6±1.1     | -1.207| 0.228  | 0.9963      | -0.038  | -0.234 to 0.310|
| SD1          | 22.4±9.9    | 22.4±9.9    | 0.851 | 0.403  | 0.9999      | -0.11   | -0.40 to 0.18  |
| SD2          | 59.3±21.2   | 59.2±21.2   | 0.907 | 0.373  | 1.0000      | -0.13   | -0.51 to 0.24  |
| ApEn         | 1.156±0.06  | 1.154±0.07  | -0.707| 0.486  | 0.9410      | 0.002   | -0.042 to 0.047|
| SampEn       | 1.511±0.24  | 1.511±0.23  | 1.118 | 0.274  | 0.9629      | -0.000  | -0.127 to 0.128|
| a1           | 1.129±0.21  | 1.133±0.21  | -2.304| 0.021  | 0.9994      | 0.005   | -0.010 to 0.020|
| a2           | 0.86±0.18   | 0.85±0.18   | -1.209| 0.238  | 0.9999      | 0.001   | -0.003 to 0.005|
HRV analysis and comparison was not carried out among the 3 cases of T6-a type data, for they lost more RRI values and could not be corrected.

4. Discussion
In this paper, the differences in the HRV analysis and the application of Polar V800 and Healink R211B are compared with the original RRI values and the various parameters of HRV. The analysis of 29 cases of original RRI values shows that if the RRI data obtained by Healink are used as a reference, the correlation coefficient of 16 cases (55%) of the Polar RRI data is 0.9999 (p = 0.094), and the mean difference is 1.1 ms with the range of 95% LoA being (-1.5, 3.8) ms. In addition, 13 cases of the RRI data have three error conditions including leak detection, false detection, and deficiency, which can be divided into four error types: T4, T5, T6-a and T6-b. T4 and T5 type errors are easier to detect and can be corrected without referencing the Healink data. Nevertheless, the correlation coefficient is still 0.9999 after the data are corrected. Among these error types, the most frequently encountered errors are the T6-a and T6-b types, which account for 10 and 28 of the total number of cases, respectively. Some studies have concluded that T6 type errors may be due to data synchronization problems and/or poor contact with the skin by the ECG electrode [16]. In any case, data of T6-a and T6-b error types cannot be corrected without referencing Healink data.

For the T6-b type data, there are only a few missing points. Assuming that there is no ECG synchronization record as a reference, HRV analysis was carried out on 26 cases of N, T4, T5 and T6-b (uncorrected) data. The Polar's HRV parameters in the time domain SDNN, RMSSD, NN50, PNN50 are in excellent agreement with the Healink data (r > 0.99, p < 0.05). Similar to Polar S810 [16], S810i [19] and V800 [21], the frequency domain parameters (VLF, LF, HF, etc.) have an excellent correlation (r > 0.99, p > 0.05) compared with the Healink data. Non-linear parameters (SD1, SD2, ApEn, SampEn, etc.) also show good correlation (r > 0.94). In the analysis of the DFA quantization parameter, the short-term fractal scale index $\alpha_1$ and the long-term fractal scale index $\alpha_2$, we found that the $\alpha_1$ and $\alpha_2$ parameters obtained from the Polar and Healink have a good correlation ($r > 0.99$). Nonetheless, for the $\alpha_1$ parameter, p < 0.05 indicates that there is a significant difference between the two devices.

5. Conclusion
The results show that when the data recorded by Polar have no, or minimal errors, there is no significant difference between the RRI data and HRV parameters obtained by the Polar V800 and the Healink R211B, except for the short time scale index $\alpha_1$. Under the premise of no missing data from the Polar V800, Polar V800 or Healink R211B, the combination of the data with the Kubios HRV software can be used to analyze the HRV time domain, frequency domain and partial nonlinear parameters. However, for scientific research or health management purposes, it should be emphasized that approximately 10% of the samples of the Polar V800 have missing RRI values, such that the entire sample data could not be used for the HRV analysis.

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