Comparison of Heart Rate Variability Assessment During Exercise from Polar RS800 and ECG

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Abstract

There are several mobile and easy to use heart rate monitors which which allow heart rate variability (HRV) analysis during exercise, but there is a need to validate them during exercise of high intensities. A previous study revealed that mean heart rate and low frequency (LF) power measurements were interchangeable between Polar RS800 and ECG, but instantaneous high frequency (HF) power presented low agreement (A) during high intensities of exercise (A<0.7). In this study we want to analyze if, even with that disagreement in HF power, the same conclusions can be extracted regarding the response of ANS to exercise from Polar HRV measurements compared to those extracted from ECG.

23 male volunteers performed an exercise stress test on a cycle ergometer while wearing a Polar RS800 device and ECG being recorded simultaneously. A time-frequency spectral analysis was performed to extract the instantaneous mean heart rate and LF and HF powers, the latter guided by respiration. Spectral components related to cardiolocomotor coupling (CC) were identified and corrected when overlapping with other components. Oxygen consumption information was used to establish 4 different intervals of different exercise intensity.

No significant differences between ECG and Polar HRV measurements were found in any interval. Both showed an increase in normalized LF power in low intensities and a significant decrease in medium to high intensities of exercise, with an opposite behaviour in the case of normalized HF. CC components reached about 20% of the total power in the last intervals, with no significant differences between ECG and Polar.

1. Introduction

Heart rate variability (HRV) remains a powerful source for autonomic nervous system (ANS) assessment by using simple and non-invasive techniques. It is used in both clinical and research environments and over a broad spectrum of disciplines concerned with autonomic control of the heart ranging from cardiology to psychology. Advances in technology have allowed the development of mobile and easy to use heart rate monitors that allow the quantification of inter-beat intervals (RR intervals) and thus the analysis of heart rate variability. Commercial devices (like Polar, Garmin, Tomtom, or Suunto heart rate monitors, among others) appear as a cheaper alternative, usually providing software which allows for an affordable and a user-friendly method to determine short-term HRV outside of the laboratory setting.

These heart rate monitors have been used by scientists for HRV analysis in sport sciences, medicine and other fields of research [1–3]. Several studies have validated these devices against different ECG systems, showing promising results at rest [4–6]. However, there are very few studies that validate HRV measurements from heart rate monitor devices during dynamic exercise of high intensity, which is characterized by a higher level of noise than in static exercise, larger variations in mean heart rate (HR) and respiratory frequency and the appearance of cardiolocomotor coupling (CC) components during high intensities.

In a previous study [12], we evaluated the agreement and reliability between the HRV analysis derived from the RR series recorded by the HR monitor Polar RS800 and HRV analysis derived from a simultaneous ECG during dynamic exercise of low, medium and high intensity. At rest, Polar measurements showed high agreement and reliability indices as expected. During high intensities of exercise, however, high frequency (HF) parameters showed low agreement.

The aim of this study is to evaluate changes in ANS during high intensity exercise using Polar measurements, despite the low agreement in HF parameters, to see whether the same information can be extracted than from measure-

 ISSN: 2325-887X DOI:10.22489/CinC.2017.206-225

ments derived directly from the ECG.

2. Methods and materials

2.1. Database

The database, described in [12], consists on ECG and Polar recordings from 23 healthy volunteers who regularly participate in sports activities. The study protocol was approved by the institutional ethics committee and was in accordance with the Declaration of Helsinki for Human Research of 1974 (last modified in 2008). Written informed consent was obtained from each subject.

All subjects completed a submaximal test on a cycle ergometer. The test was divided into three different phases: resting, exercise and recovery phase. During the resting phase, the subjects were continuously monitored while seated at rest for 5 min. The exercise phase started on the cycle ergometer at 75 W work load, increasing at a rate of 25 Wmin-1. The cadence frequency was fixed at 80 rpm. This phase lasted until the subject reached his 90% maximum heart rate, which was determined in previous tests by a physician. Then, the work load was kept constant for two more minutes. The recovery phase consisted of 5 min of pedalling at free cadence.

Information about respiratory frequency and oxygen consumption ($\dot{V}O_2$) were obtained by an open-circuit sampling system (Oxycon Pro, Jaeger-Viasys Healthcare, Hoechberg, Germany). The metabolic cart was calibrated with a known gas mixture (16% oxygen, O_2, and 5% carbon dioxide, CO_2) and volume prior to the first test each day as recommended by the company. Both respiratory frequency and $\dot{V}O_2$ data were interpolated at 4 Hz and low-pass filtered with a cut-off frequency of 0.01 Hz to obtain $f_{\mathrm{R}}(n)$ and $d_{\dot{\mathrm{V}}\mathrm{O}_2}(n)$ series, respectively. Five different intervals dependant on $d_{\dot{\mathrm{V}}\mathrm{O}_2}(n)$ are defined: resting phase (I_{B}), increments up to 60%, 80% and 100% of the consumed oxygen (I_{60}, I_{80}, I_{100}) and recovery phase (I_{R}).

In addition to the ECG recording, RR intervals were recorded beat-to-beat using an HR monitor (RS800, Polar Electro Oy, Kempele, Finland) which uses a sampling frequency of 1000 Hz for the ECG signal. RR intervals from the ECG ($\mathrm{RR}_{\mathrm{ECG}}$) were obtained as the difference of each consecutive beat occurrences. RR intervals from Polar ($\mathrm{RR}_{\mathrm{POL}}$) were directly obtained from the device. The delay between $\mathrm{RR}_{\mathrm{ECG}}$ and $\mathrm{RR}_{\mathrm{POL}}$ was estimated as that lag which maximizes their cross correlation. Subsequently, the two series were synchronized by correcting this delay.

2.2. Data analysis

The instantaneous heart rate signal, $d_{\mathrm{HR}}(n)$, is derived from both RR intervals series, following a method based on the TVIPFM model, and sampled at 4 Hz. This signal is high-pass filtered to remove the mean heart rate $d_{\mathrm{HRM}}(n)$ (very low frequency components) and it is also corrected by it: $m(n) = (d_{\mathrm{HR}}(n) - d_{\mathrm{HRM}}(n))/d_{\mathrm{HRM}}(n)$ [8].

The smoothed pseudo Wigner-Ville distribution (SPWVD) was applied to $m(n)$ to estimate the time-varying spectral properties of both HRV signals [9], with the same parameters used in [10]. The instantaneous power in the low and high frequency band, $P_{\mathrm{LF}}(n)$ and $P_{\mathrm{LF}}(n)$ respectively, was extracted throughout the entire exercise test. Low frequency band ranged from 0.04 to 0.15 Hz. The high frequency band was centered on $f_{\mathrm{R}}(n)$ with a bandwidth of 0.25 Hz. The lower limit of the HF band was never below 0.15 Hz, and the upper limit was never above the half of mean heart rate [10]. Figure 1 shows an example of $P_{\mathrm{HF}}(n)$ from ECG and Polar during the resting phase and exercise phase (I_{60} to I_{100}). It can be seen that both powers are very similar at rest, but the differences become more evident during exercise.

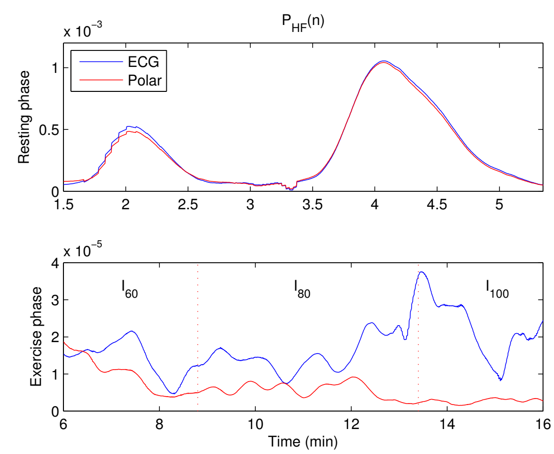

Figure 1. Example of $P_{\mathrm{HF}}(n)$ obtained from ECG and Polar during rest and exercise phase. Intervals I_{60}, I_{80} and I_{100} represents 0-60%, 60-80% and 80-100% of $d_{\dot{\mathrm{V}}\mathrm{O}_2}(n)$, respectively.

CC components are related to the cadence frequency, $f_{\mathrm{C}}(n)$, which is fixed at 80rpm. Since the intrinsic sampling frequency of HRV is the HR, when $f_{\mathrm{C}}(n)$ exceeds half the mean HR, aliasing occurs and aliased components appear in the visible part of the spectrum [3]. There are two main aliased components (denoted AF1 and AF2) and their powers are denoted as:

- $P_{\mathrm{AF1}}(n)$: in a band centered at $d_{\mathrm{HRM}}(n) - f_{\mathrm{C}}(n)$ with a bandwidth of 0.125 Hz.
- $P_{\mathrm{AF2}}(n)$: in a band centered at $-d_{\mathrm{HRM}}(n) + 2 \cdot f_{\mathrm{C}}(n)$ with a bandwidth of 0.125 Hz.

Figure 2 shows an example of a time-frequency map showing some of the spectral components of HRV, as well as an overlapping between HF and the aliased components.

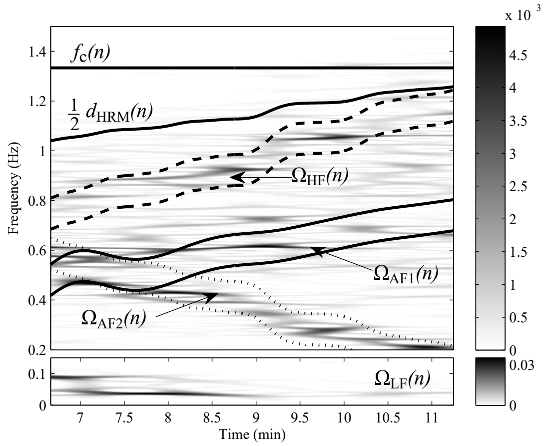

Figure 2. Example of a time-frequency map showing some of the spectral components of HRV (HF, CF, AF1 and AF2) during the exercise phase.

When components related to cardiolocomotor coupling overlap with HF band, it makes difficult to interpret it as a measure of respiratory sinus arrhythmia. A method was proposed in [11] and expanded in [12] to correct the powers which takes into account the percentage of overlap between the spectral bands and the relative power prior the overlapped area.

Due to the large changes of the total power for all bands, each instantaneous power is normalized by the instantaneous total power, which is defined as:

$$P_{\text{TOT}}(n) = P_{\text{LF}}(n) + P_{\text{HF}}(n) + P_{\text{CC}}(n) \qquad (1)$$

with $P_{\text{CC}}(n)$ being the sum of all components related to cardiolocomotor coupling, and both HF and CC components being corrected in the overlapped areas. Then, the studied power parameters are:

$$\overline{P}^{\text{I}}_{\mathcal{A}} = \frac{1}{N_{\text{I}}} \sum_{n \in I} \frac{\hat{P}_{\mathcal{A}}(n)}{P_{\text{TOT}}(n)}, \quad I \in \{I_{\text{B}}, I_{60}, I_{80}, I_{100}, I_{\text{R}}\} \qquad (2)$$

Where N_{I} denotes the length of the interval I, and the subindex $\mathcal{A}$ indicates the chosen spectral component. Note that $\overline{P}^{\text{I}_B}_{\text{CC}}$ is an exception and is not defined, since at rest there is no power related to cardiolocomotor coupling.

2.3. Statistical analysis

Parameters $\overline{P}^{\text{I}}_{\text{LF}}$, $\overline{P}^{\text{I}}_{\text{HF}}$ and $\overline{P}^{\text{I}}_{\text{CC}}$ were obtained for every interval. A Kolmogorov test showed that they did not follow a normal distribution. Therefore, a paired Wilcoxon test was applied for every parameter to study the differences Polar and ECG measurements to see if they show the same ANS changes in the different intervals. The difference is considered to be significantly different from zero when $p < 0.05$. Moreover, a Friedman test is applied for every parameter within the same type of measurements, followed by post-hoc comparisons to study the changes through the test.

3. Results

Figure 3 shows parameters $\overline{P}^{\text{I}}_{\text{LF}}$, $\overline{P}^{\text{I}}_{\text{HF}}$ and $\overline{P}^{\text{I}}_{\text{CC}}$ in the different intervals from the Polar and ECG measurements. LF power is always higher in Polar measurements, while HF power is always lower with respect to the ECG measurements, but no significant differences were found between ECG and Polar measurements.

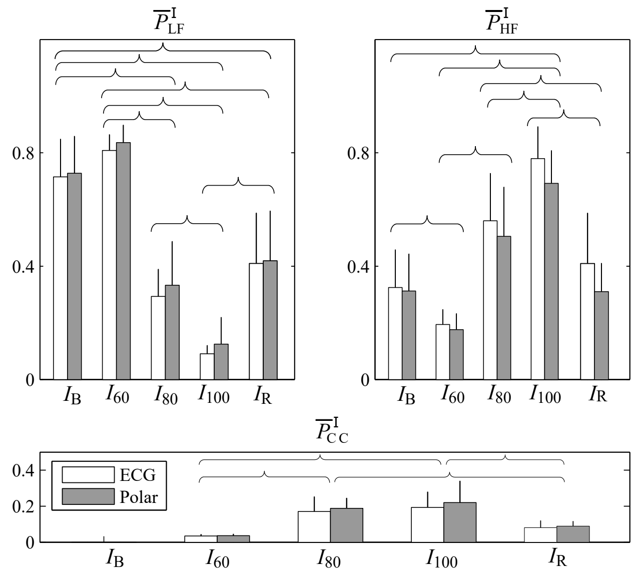

Figure 3. Median and MAD of $\overline{P}^{\text{I}}_{\text{LF}}$, $\overline{P}^{\text{I}}_{\text{HF}}$ and $\overline{P}^{\text{I}}_{\text{HF}}$ in intervals I_{R}, I_{60}, I_{80} and I_{100} for the ECG and Polar measurements. Brackets denote significant differences (p value $<$ 0.05).

Regarding the trend of the HRV measurements, $\overline{P}^{\text{I}}_{\text{LF}}$ increases at the beginning of the exercise (although it is not significant in this test), then it decreases again when the exercise load gets more intense, and then it increases in the recovery phase. All pair of intervals, with the exception of the pairs I_{B} and I_{60}, and I_{80} and I_{R}, present significant differences. $\overline{P}^{\text{I}}_{\text{HF}}$ gets significantly reduced at I_{60}, then it increases and it decreases again in the recovery phase. I_{B} is significantly different to all intervals except I_{80} and I_{R}; I_{60} is significantly different to all intervals except I_{R}; and I_{100} is significantly different to all intervals. There is a significative increase from I_{60} to I_{80} in $\overline{P}^{\text{I}}_{\text{CC}}$, and a significative decrease from I_{100} to I_{R}.

4. Discussion

This study has shown that, besides the reported low values of reliability and agreement coefficients for HF power during high intensities of exercise in previous works, no significant differences were found in LF, HF and CC components when calculating power parameters as the mean value in the intervals of interest and correcting the CC components, regardless the intensity of exercise.

Both Polar and ECG measurements showed an increase in normalized LF power in low intensities, a significant decrease in medium to high intensities of exercise and then a significant increase in the recovery phase; with an opposite behaviour in the case of normalized HF. This behaviour supports the findings in other works, where it is shown that at the beginning of the exercise there are both a parasympathetic withdrawal and an augmentes sympathetic activity; but later on, during high intensities, HF increases due to the mechanical effect of breathing. There is also a greater cardiolocomotor power near the peak of exercise: CC components reached about 20% of the total power in the last exercise intervals and about 10% in the recovery phase.

This suggests that the same conclusions regarding the ANS response to exercise can be derived analyzing HRV derived from RR series provided by Polar than from RR series obtained from the ECG.

5. Conclusion

A Polar RS800 device was validated in 23 healthy male volunteers during an exercise test. A high resolution ECG was simultaneously recorded to extract the RR intervals and use them as a reference. A time-frequency spectral analysis was performed to extract the mean HR and the power of LF and HF components, the latter centered on the respiratory frequency. Although the performance of the HF measurements from the Polar device had been reported to decrease as the level of the exercise increases, with reliability and agreement coefficients around 0.5, the total power in the HF band in the analyzed interval was found to be not significantly different from the ECG measurement.

Acknowledgements

This work has been supported by Centro de Iinvestigación Biomédica en Red - Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN) through Instituto de Salud Carlos III, by MINECO and FEDER under project TIN2014-53567-R and DPI2016-75458-R, and by Aragón Gobernment (Spain) and European Social Fund through Grupo Consolidado Biomedical Signal Interpretation and Computational Simulation (BSICoS), Ref: *T96*. The computation of some parts of this work was performed at the High Performance Computing platform of the NANBIOSIS ICTS, CIBER-BBN and Aragón Institute of Engineering Research (I3A), Zaragoza, Spain.

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