Respiration Differentially Modulates HRV Obtained from Arterial Pressure Wave and Electrocardiogram

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Abstract

We assessed the variability of the series resulting from the subtraction of the RR intervals from the pulse intervals (PI-RR) and examined how it was affected by two maneuvers that modify the cardiac autonomic status. The RR, PI, PI-RR and respiratory series of 20 healthy subjects were computed during three 5-min conditions: supine, standing and exercise. High frequency (HF) and low frequency (LF) components and coherence were computed using spectral and cross-spectral analysis. In the three conditions power spectra of the PI-RR series were distributed exclusively in the HF band and were highly coherent with the respiratory spectra. The $HF_{PI\text{-}RR}$ *to* HF_{RR} *ratio was 14% in supine, 34% in standing and 262% in exercise. The spectral measures obtained from the RR intervals and PI are not equivalent since the subtraction PI-RR yields a residual series with only HF power due to the greater respiratory effect on PI, exerted by a non-neural mechanism which is subtle in supine, relevant in standing and very important in exercise.*

1. Introduction

In most studies, time- and frequency-domain analyses of heart rate variability (HRV) are performed on RR interval series. However, while a number of authors have documented that the pulse intervals (PI) series obtained from photoplethysmographic signals is a surrogate for RR intervals to compute HRV indexes [1-4], others have found disagreement between the HRV indexes derived from both types of intervals [5-8]. Therefore, the equivalence between the HRV indexes derived from RR intervals and from PI remains controversial. To address this issue, we assessed the variability of the series resulting from the subtraction of the RR intervals from the PI (PI-RR), examined its relationship with respiration and evaluated how it was affected by two maneuvers that modify the cardiac autonomic modulation, postural change and dynamic exercise.

2. Methods

2.1. Subjects

Twenty healthy and sedentary subjects, 13 men and 7 women, were studied. Mean age, height and weight were 23.6±2.3 years, 165±8 cm and 62.6±11.0 kg respectively. Health status was evaluated by resting ECG, spirometry and clinical history. Their written informed consent was requested to participate.

2.2. Protocol

Volunteers visited the laboratory twice. The first time, their health status and anthropometric characteristics were evaluated, and in the second visit the experimental stage was performed. The 5 min long maneuvers employed induce stationary heart rate states and specific changes in the cardiac autonomic activity [9]. These were: postural change from supine to standing position, which elicits a sympathetic activity increase, and a single bout of 100W cycling exercise, that provokes a substantial vagal withdrawal. Supine position was considered the control condition. ECG, non-invasive blood pressure and respiratory movements were recorded during each condition.

2.3. Recorded variables and signal acquisition

ECG was detected at the CM5 bipolar derivation using a bioelectric amplifier (Biopac Systems). None of the participants presented ectopic beats. Non-invasive blood pressure was measured by Finapres (Ohmeda). The respirogram was obtained by means of a stretching pneumograph (Nihon Kohden). ECG, blood pressure and respirogram signals were digitized at a sampling rate of 2 kHz via an acquisition and display system (Biopac Systems). Since the difference between the two types of intervals was expected to be minimal, a resolution of 0.5 ms was used.

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2.4. Data processing

Peak values of the R wave and systolic point of the arterial pressure pulse were detected to generate the RR intervals and PI series respectively. The RR intervals were subtracted beat-by-beat from the PI [7] to form the PI-RR series. All series were cubic-spline interpolated, resampled at 4 Hz and detrended. The power spectra of the series were computed by Welch algorithm. With the exception of respiratory series, spectral power was integrated in the low frequency (LF) band, from 0.04 to 0.15 Hz, and in the high frequency (HF) band, from 0.15 to 0.4 Hz (extended to 1 Hz only for exercise) to obtain, in absolute units, the respective components of each series: RR (LF_{RR} and HF_{RR}), PI (LF_{PI} and HF_{PI}) and PI-RR ($LF_{PI\text{-}RR}$ and $HF_{PI\text{-}RR}$). The square root of the ratio between the $HF_{PI\text{-}RR}$ and the HF_{RR} components ($HF_{PI\text{-}RR}/HF_{RR}$) was also computed. Mean frequency of the HF band of the respiratory (MF_{resp}) and PI-RR ($MF_{PI\text{-}RR}$) spectra was calculated as the centre of gravity of the respective spectrum [10]. Coherence function between the PI-RR and respiratory spectra was obtained by cross-spectral analysis. Coherences greater than 0.5 were considered significant.

2.5. Statistical analysis

Data were expressed as mean ± standard deviation. Differences among the HRV spectral indexes during the conditions were tested by analysis of variance for repeated measures. Post-hoc pairwise comparisons were performed by the Tukey test. For comparisons between the measures derived from RR intervals and PI, paired t-test was employed. Linear correlation between the pooled HF_{RR} and $HF_{PI\text{-}RR}$ powers was computed. Statistical significance was accepted at $p<0.05$.

3. Results

Figure 1 depicts representative examples of the PI and RR intervals series and their respective power spectra during the three experimental conditions. The PI series presented greater variability than the RR intervals, and the HF_{PI} components were larger than the HF_{RR} powers. These differences were small in supine, greater in standing and greatest during exercise (Fig. 1).

Mean values of HF_{PI} component were larger than HF_{RR} (Table 1) in the three conditions ($p<0.001$), while the mean LF_{PI} and LF_{RR} components were not different ($p>0.05$). With respect to supine, HF_{RR} component decreased ($p<0.001$) in standing and declined abruptly in exercise (Table 1).

Only the mean values of LF_{RR} power of exercise and supine were different ($p<0.001$). In standing, both LF_{RR} and LF_{PI} components were greater than the respective HF_{RR} and HF_{PI} components ($p<0.05$). In exercise, LF_{RR} power was greater than HF_{RR}, but LF_{PI} power was less than HF_{PI} power ($p<0.001$).

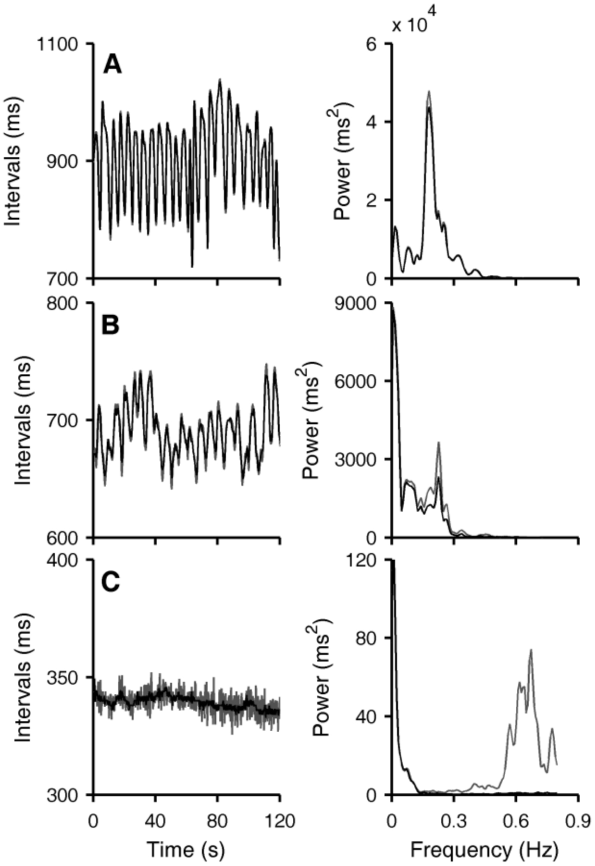

Figure 1. Representative example of PI (grey line) and RR intervals (black line) series along with their respective power spectra during the experimental conditions: (A) supine, (B) standing and (C) exercise.

Table 1. HF and LF components of the RR intervals and PI in the three experimental conditions. Data are mean±sd, N=20.

	Supine	Standing	Exercise
HF_{RR} (ms^2)	309±179	94±63†	2±2†
HF_{PI} (ms^2)	333±197*	124±78†*	9±6†*
LF_{RR} (ms^2)	265±164‡	244±139‡	4±3†‡
LF_{PI} (ms^2)	269±169‡	257±147‡	4±3†‡

† $p<0.001$ with respect to supine; * $p<0.001$ between RR and PI; ‡$p<0.05$ between LF and HF components.

Figure 2 shows a typical example of the PI-RR series, PI-RR power spectra, respiratory spectra and coherence between PI-RR and respiratory spectra during the three experimental conditions. Note that in all conditions the power spectra of the residual PI-RR series were distributed only in the HF band and presented high coherence with the respiratory spectra.

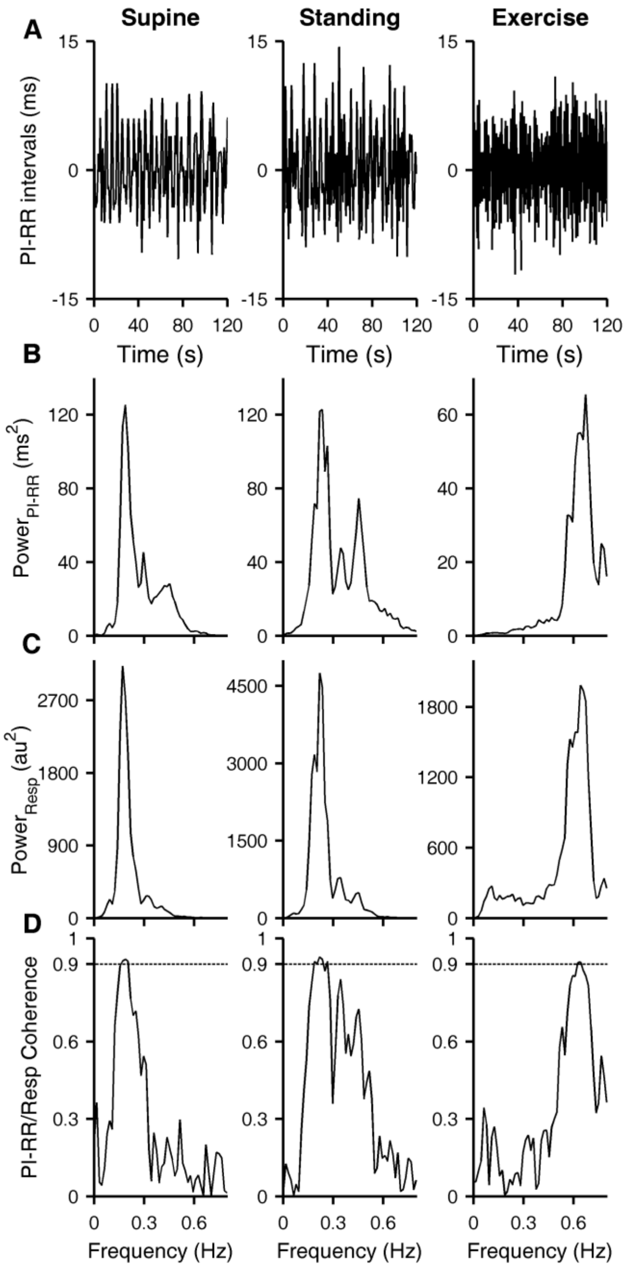

Figure 2. Typical examples of (A) PI-RR time series, (B) power spectra of the PI-RR series, (C) power spectra of respiration and (D) coherences between PI-RR and respiratory spectra in the three experimental conditions.

Mean values of the HF_{PI-RR} power were not different ($p>0.05$) between conditions (Table 2). MF_{PI-RR} was not different ($p>0.05$) from MF_{Resp} in the three conditions (Table 2). Coherence between the respiratory and PI-RR power spectra was greater than 0.90 in the three conditions. The HF_{PI-RR}/HF_{RR} ratio was a small fraction in supine, increased in standing and reached its maximum value in exercise (Table 2). The means of this measure were different between conditions ($p<0.015$).

Table 2. Spectral indexes of PI-RR variability and respiration. Data are mean±sd, N=20.

	Supine	Standing	Exercise
HF_{PI-RR} (ms^2)	6±3	9±5	8±6
MF_{PI-RR} (Hz)	0.28±0.03	0.28±0.04	0.67±0.06†
MF_{Resp} (Hz)	0.27±0.04	0.28±0.04	0.61±0.08†
Coherence	0.90±0.04	0.94±0.04	0.93±0.03
HF_{PI-RR}/HF_{RR}	0.14±0.05	0.34±0.14†	2.62±1.33†

† $p<0.015$ with respect to supine.

The relationship between the HF_{PI-RR} and HF_{RR} components had a very weak and non significant ($p>0.05$) correlation (Fig. 3).

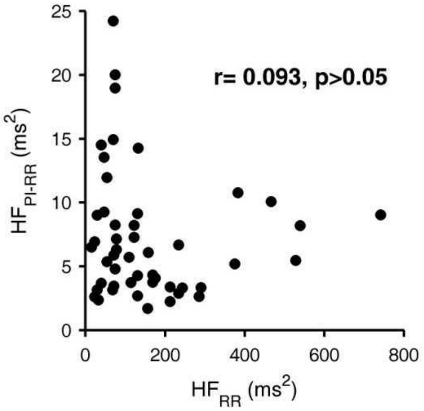

Figure 3. Relationship between the HF components of PI-RR series and RR intervals.

4. Discussion and conclusions

Subtracting RR intervals from PI yields a residual time series which spectral power is exclusively distributed over the HF band and is strongly correlated with the respiratory spectrum but not with HF_{RR} power. These findings conclusively demonstrate that respiration modulates more the PI than the RR intervals through a non-neural mechanism.

Photoplethysmographic-based methodologies have been widely used in many different clinical settings, because they offer a simple, useful and compact way to measure several physiological parameters [8]. This is one of the reasons for the growing interest in investigating the validity of using PI as a surrogate for RR intervals to perform time- and frequency-domain analysis of HRV [1,3,4]. However, several studies have reported differences between the indexes derived from the two kinds of intervals. There is clear evidence of their non-equivalence. Janssen et al. [5] showed that the mean of all computed HF_{PI} was 136% of that of the atrial electrogram. Similarly, Dawson et al. [6] and Constant et al. [7] have documented differences between the power spectra of both types of intervals, primarily due to a larger HF_{PI} component. The findings of the present study are in agreement with these studies.

The notion that the HF_{PI-RR} component is due to a modulatory effect of respiration is supported by two evidences: 1) the mean frequencies of the HF_{PI-RR} and of the respiratory spectra are similar, and 2) the respiratory spectra are highly coherent with the PI-RR ones, with peak coherences at their mean frequencies. Also, the concept that the additional respiratory effect on the PI is of non-neural nature is documented by: 1) the greater reduction of HF_{RR} than HF_{PI} in exercise, and 2) the lack of a linear relationship between the pooled HF_{PI-RR} and HF_{RR} components despite that the used maneuvers induce different degrees of vagal withdrawal. Thus, HF_{PI-RR} power can be considered a measure of the mechanical respiratory influence. This effect is probably exerted through a thoracic-cardiovascular capacitive coupling, similar to the one proposed by Saul et al. [11] to explain the respiratory modulation of arterial blood pressure. Given the observed constancy of the HF_{PI-RR} power throughout the conditions, the changes in the HF_{PI-RR}/HF_{RR} ratio as an indicator of the relative magnitude of the mechanical respiratory effect (Table 2) are due to the dramatic alteration of the HF_{RR} values (Table 1). Thus, the contribution of the mechanical respiratory effect to the HF_{PI} power is subtle in supine (14%), relevant in standing (34%) and very important in exercise (262%).

When the HRV analysis is performed using the RR intervals, the LF_{RR} component is greater than the HF_{RR} component during exercise (Table 1). Due to the additional non-neural respiratory modulation on PI, in this condition the amplitude of the HF_{PI} component is greater than the amplitude of the LF_{PI} component and also is four times greater than the HF_{RR} component (Fig. 1, Table 1), as previously reported by Charlot et al [8]. The inversion of the ratio between LF and HF components could be misinterpreted as a vagal activity increase, a situation clearly anomalous during exercise.

We speculate that in scenarios where the PI and RR intervals variabilities are normal, the difference between their spectral indexes will be small. But in situations where the variability of RR intervals is reduced –such as during exercise or during most cardiological diseases–, the difference becomes remarkable and should not be ignored. In such cases, the HF_{PI} component would be almost exclusively due to the mechanical respiratory effect, not to vagal modulation. We therefore discourage the usage of PI as a surrogate for RR intervals for spectral HRV analysis, especially in conditions that induce a reduced RR interval variability, where the non-neural respiratory influence can become the main source of variability. In addition, this influence is probably present in any period that involves the arterial pulse wave, e.g. the pulse transit time [12]. However, it should be kept in mind that the spectral HRV indexes derived from the PI include additional respiratory-related information that deserves further research.

In conclusion, our results indicate that the HRV indexes obtained from RR intervals and PI are not equivalent during the three conditions employed, because the respiratory influence is greater in the latter via an additional mechanical modulation. This effect is clearly indicated by the HF power of the PI-RR series, especially during exercise.

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