Effects of Pedaling on the High Frequency Components of HRV during Exercise

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Abstract

The aim of our study was to prove the existence of a spectral peak at the pedaling frequency in the heart rate spectra, during exercise test on the cycloergometer, and to describe its characteristics. This was done by studying four young healthy volunteers (2M/2F, 18-22 yrs) while pedaling on a cycloergometer with incremental workloads, by mean of a 3-lead ECG and a 7 TV-camera optoelectronic device for recording pedal movements and respiratory movements of the thorax.

A clear spectral peak in the HRV spectrum at the pedaling frequency appeared for certain workloads in all subjects. The power of this peak represented a significant fraction of the power of the respiratory peak. Since the overall displacement of the chest was the same regardless of the work load, we can exclude that the spectral peak at the pedaling frequency is due to a motion artifact, and we can rather hypothesize that it is related to the muscle pump mechanism.

1. Introduction

Spectral analysis of Heart Rate Variability (HRV) is a very popular tool to investigate the cardiac autonomic nervous system. In the past, several studies have clearly demonstrated that the spectral power at frequencies higher than 0.15 Hz (the high frequency, HF, band) are almost completely due to vagal modulations of heart rate induced by the respiratory activity [1].

Recently, however, the existence of a spectral peak in the HF band, at frequency higher than the respiratory frequency, has been anecdotically reported during exercise test on the cycloergometer [2,3].

The aim of our study was to gather a deeper understanding of this phenomenon. In particular, we wanted to investigate if and how frequently a pedaling spectral peak appears in the HRV spectrum during exercise tests on the cycloergometer

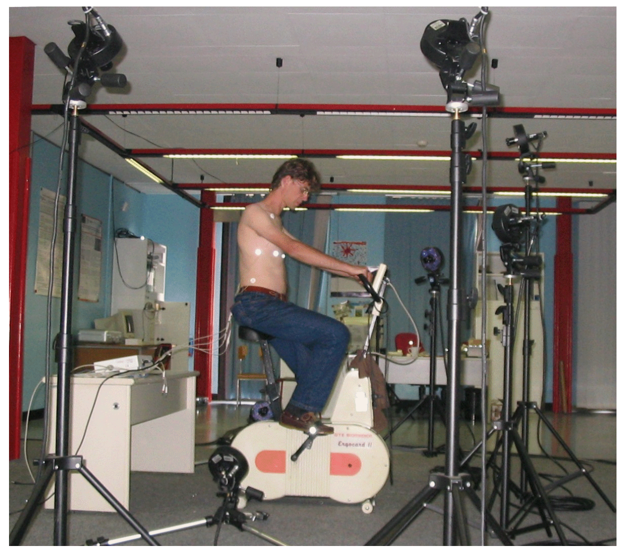

Figure 1. Experimental set up: thorax and pedal movements were estimated by an optoelectronic device.

2. Methods

A. Experimental set up

The experimental set up (figure 1) included an electrocardiograph (Cardioline Delta 1 PLUS), a 7 TV-camera optoelectronic device for motion analysis (SMART-e BTS S.r.l. Milan) and a cycloergometer (Ergocard II OTE BIOMEDICA). We placed 4 electrodes on the thorax to derive a standard 3-lead ECG, and 5 passive reflective markers along the anterior semiperimeter of the chest at the height of the sixth rib, to measure respiratory movements by means of the optoelectronic device. A 6th reflective marker was placed on a pedal of the cycloergometer to measure the pedal movement. ECG was sampled at 960 Hz, while thorax and pedal movements were sampled at 60 Hz.

B. Data Collection.

We studied four young healthy volunteers (age between 18 and 22 yrs.), two males and two females, one fit and one sedentary for each gender category.

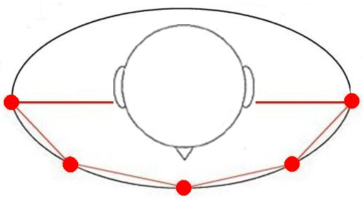

Figure 2**.** Location of the 5 markers on the thorax.

After 1 min of rest sitting on the cycloergometer, each subject was asked to perform two trials, at 60 and 70 rpm pedaling frequencies respectively, with incremental workload starting at 50W with 25W increments/minute until exhaustion. If a spectral peak synchronized with the pedaling frequency was identified (see “signal analysis” below), the subject was asked to perform a third trial pedaling at 70 rpm breathing at 24 breaths/min following a metronome. This was done to avoid the possible interference of harmonics related to the respiratory driven HR peaks in regards to the spectral peak at the pedaling frequency.

C. Signal Analysis

We derived a respiratory signal as the length of the thorax semiperimeter from the 3D movements of the 5 markers on the thorax. This was done by means of an appropriate MATLAB function which calculated the distance between consecutive markers and the length of the thorax semiperimeter summing all these distances. This function also provides the position of the geometric center of the chest. The respiratory signal and the vertical component of the movement of the marker on the pedal were oversampled at the same frequency of the ECG (960 Hz).

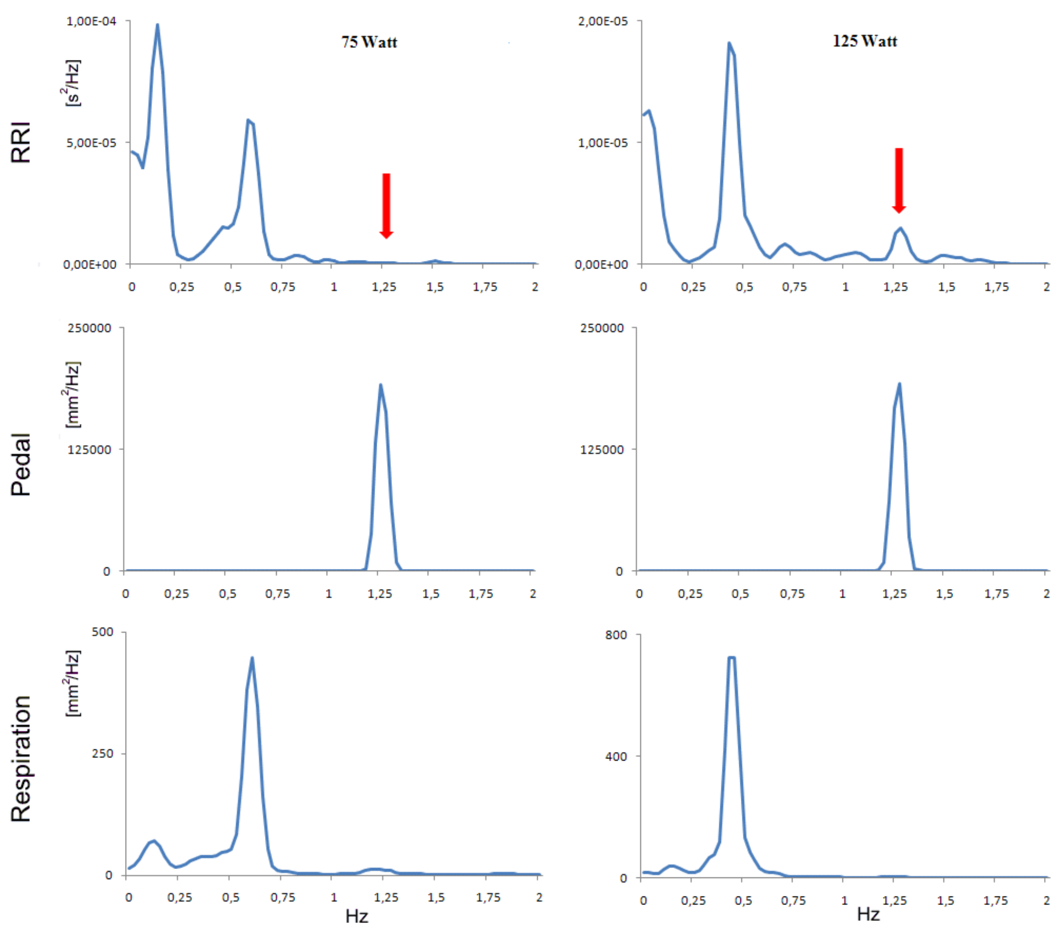

Figure 3. Spectra of RRI and of respiratory and pedal movements in one subject pedaling at 75 watt (*left*) and at 125 watt (*right*). A pedaling peak is identified only at 125 watt.

The best ECG lead was visually selected. The beat by beat series of R-R intervals (RRI) was derived by identifying each R peak by means of a detection algorithm based on the ECG band-pass filtering (to extract the QRS complex), differentiation, squaring and comparison with an adaptive threshold [4].

The RRI beat-to-beat series was interpolated and evenly sampled at 100 Hz. For each incremental step of 1 minute, we calculated the FFT power spectrum of the RRI resampled series, of the respiratory signal, and of the pedal movement. Breathing frequency and pedaling frequency were identified as the position of the maximum spectral peak in the respiratory and pedal spectra.

When a peak at the pedaling frequency appeared in the HRV spectrum during trials 1 and 2, we identified this peak as a pedaling-related spectral peak only if its power was greater than 5% of the power associated to the respiratory peak.

We expressed the heart rate at which the pedaling peak appeared as a percentage of the maximal cardiac frequency. The latter has been calculated with Tanaka's formula:

$f_c^{max} = 208 - (0.7 \text{ x age})$.

Examples of spectra of RRI series, and of respiratory and pedal movements, during two incremental steps at different workloads (75W and 125W) are illustrated in figure 3. In this figure, the pedaling peak is identified in the RRI spectrum only at 125W.

3. Results

Clear spectral peaks at the pedaling frequency were observed in all four subjects at specific workloads. Figure 4 shows the loads at which the pedaling peak has appeared in the HRV spectrum in at least one trial, separately for each subject. The loads are higher in males than in females (around 150W for males and 100W for females).

The heart rate for which the peak appeared was on average around 80% of the maximal cardiac frequency, ranging from a minimum of 70% and a maximum of 95%.

In the bar chart of figure 5 we show the power associated to the pedaling component in the HRV spectrum for each subject. The power was particularly intense reaching 28% (+11%), M (+SD), of the respiratory peak power, when measured during paced breathing. In one trial the peak appeared at the lowest load (50W) while in two trials it appeared at the maximum load reached by the subject.

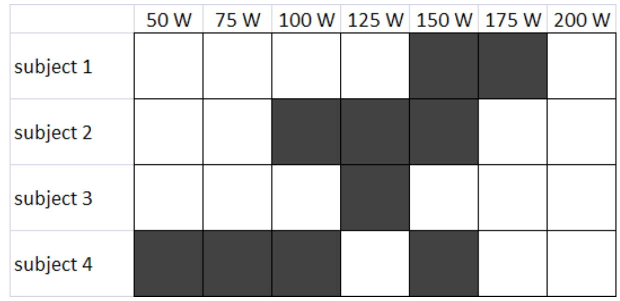

Figure 4. Loads at which pedaling peak appeared in at least one trial for each subject. Subject 1 was the male fit one, subject 2 was the male sedentary one, subject 3 was the female fit one, subject 4 was the female sedentary one.

In all the four subjects the pedaling peak was observed also in the third trial. This confirmed the results obtained in the first two trial, excluding that the peak could be due to higher harmonics of breathing.

4. Discussion and conclusions

Our study demonstrates, for the first time, that pedaling actually influences high frequency components of HRV and produces evident spectral peaks synchronized with the pedaling frequency.

Interestingly, the heart rate at which the pedal peak was observed was close to 80% of the maximal heart rate. Since the anaerobic threshold approximately corresponds to the 80% of the maximal heart rate, the phenomenon appears to mainly occur close to the anaerobic zone.

Concerning the possible origin of this peak, we also excluded the possibility that the pedaling peak is actually caused by a movement artifact. Indeed, in an ancillary test we measured the position of the geometric center of the chest's section (see methods, data not presented), and we observed that the overall displacement of the chest was not related to the occurrence of the pedaling peak. This excludes the possibility that the pedaling peak is due to a motion artifact, and we can rather speculate that it is related to a more physiological mechanisms, such as the muscle pump. This hypothesis remains to be further investigated.

Our results may have also a methodological impact. Indeed, the power of the respiratory-driven HR spectral peak is commonly approximated by computing the integral of the power in the whole HF band. Our data clearly indicates that during exercise on the cycloergometer [5-8] this approach may lead to errors since the occurrence of the pedaling peak may significantly increase the overall spectral power in the HF band.

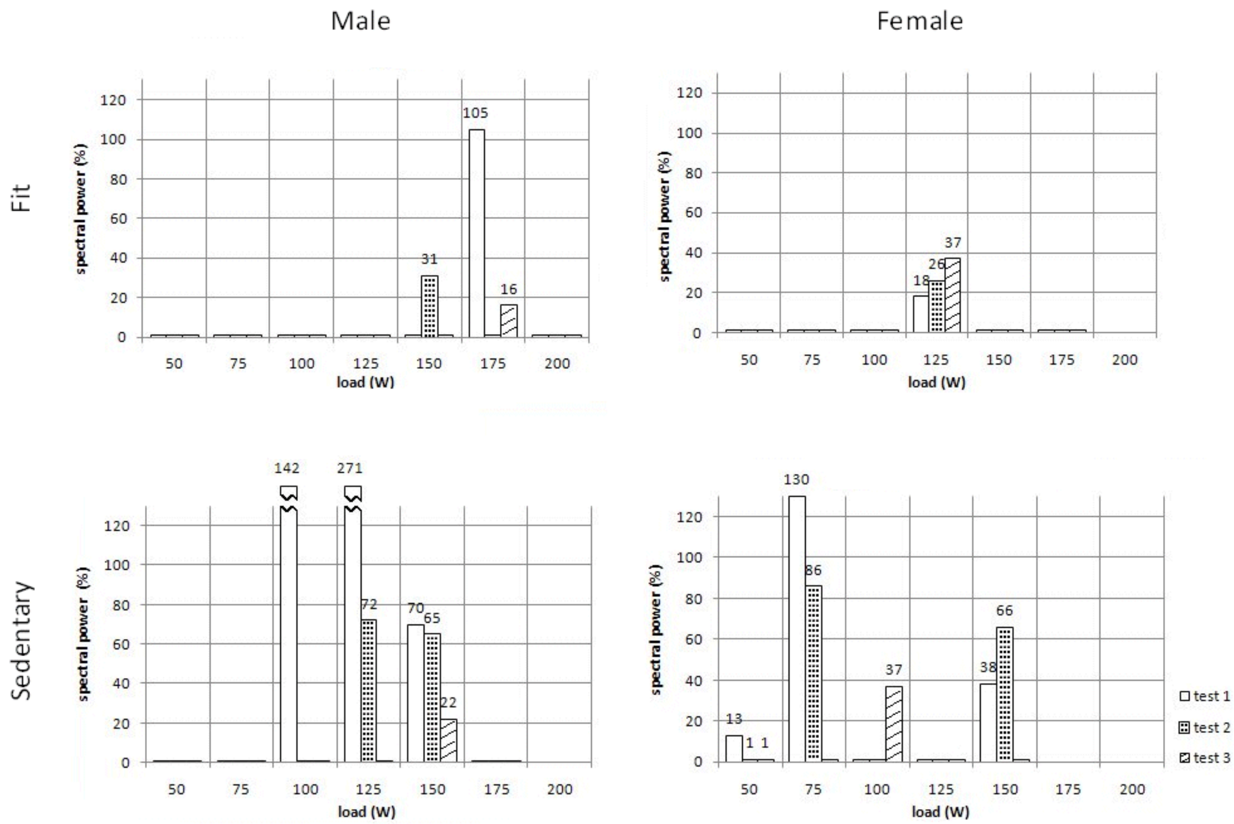

Figure 5**.** Power associated with the pedaling component in the HRV spectrum, for the four subjects. For each load, bar graphs display the spectral powers in trial 1 (white bar), trial 2 (dotted bar) and trial 3 (dashed bar). Loads are expressed in Watt and pedaling powers as percent of breathing powers.

References

[1] Task Force of ESC and NASPE. Heart Rate Variability. Standards of measurement, physiological interpretation, and clinical use. *Eur. Heart J.* 1996; 17:354-381.

[2] Bailon R, Laguna P, Mainardi L, Sörnmo L. Analysis of Heart Rate Variability Using Time-Varying Frequency Bands Based on Respiratory Frequncy. *Conf. Proc. IEEE Eng Med Biol Soc* 2007; 1:6674-7.

[3] Meste O, Blain G, Bermon S. Influence of the pedaling frequency on the Heart Rate Variability. *Conf. Proc IEEE Eng Med Biol Soc* 2007; 1:279-282.

[4] Kohler BU, Hennig C, Orglmeister R, The principles of software QRS detection. IEEE Eng Med Biol Mag 2002 Jan;, 21(1):42-57

[5] Anosov O, Patzak A, Kononovich Y, Persson P. High-frequency oscillations of the heart rate during ramp load reflect the human anaerobic threshold. European journal of applied physiology, 2000, 83:4-5,388-394;

[6] Cottin F, Leprêtre PM, Lopes P, Papelier Y, Médigue C, Billat V. Assessment of ventilatory thresholds from heart rate variability in well-trained subjects during cycling. Int J Sports Med. 2006, 27(12):959-67

[7] Banach T, Grandys M, Juszczak K, Kolasińska-Kloch W, Zoładź J, Laskiewicz J, Thor PJ. Heart rate variability during incremental cycling exercise in healthy untrained young men. Folia Med Cracov. 2004;45(1-2):3-12

[8] Perini R, Veicsteinas A. Heart rate variability and autonomic activity at rest and during exercise in various physiological conditions. Eur J Appl Physiol. 2003, 90(3-4):317-25].

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