

BAROREFLEX MONITORING OF ORTHOSTATIC TESTS IN COSMONAUTS A TIME – FREQUENCY ANALYSIS

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Abstract: Orthostatic tests allow studying the autonomic nervous system and in particular the baroreflex. We developed a time frequency analysis of beat by beat variations of blood pressure and RR interval that follows during the test, with non invasive tools, indexes of activity of the autonomic nervous system and of the baroreflex. We applied with success this method to lower body negative pressure tests in one cosmonaut during a space flight. Further studies are necessary to evaluate this method as a predicting tool of syncope, the main risk of orthostatic tests.

Keywords : Orthostatic hypotension, cardiovascular deconditioning, weightlessness, Lower body negative pressure, beat to beat analysis, time-frequency analysis.

I. INTRODUCTION

Orthostatic tests like stand test, tilt tests or LBNP (Lower Body Negative Pressure) are widely used for syncope diagnosis in patients [1] or for scientific purpose to study cardiovascular regulation [2]. A LBNP test induces with a depression applied below the iliac crest, fluid shift (blood and interstitial fluids) towards the lower part of the body. It simulates orthostatic position in a lying subject. Standing is also accompanied with fluid accumulation in the lower part of the body. LBNP tests stimulate the cardiovascular system, and in particular the baroreflex regulation loop. The depression is usually maintained during several minutes and can reach different levels. During a fixed level of depression, the fluid shift is progressive so the cardiovascular responses can not be considered stationary. Analysis of LBNP and of the other orthostatic tests is difficult because of their dynamical aspect. The risk of these orthostatic tests is syncope by acute decrease of blood pressure (hypotension) and we have no tool to predict it. Nowadays, the clinical survey remains based on subject feeling and on the evolution of heart rate and blood pressure that have very weak predicting information.

Spectral analysis of beat by beat heart rate and blood pressure variability gives indications on cardiovascular regulation. It measures the two autonomic nervous system activity (ortho- and parasympathetic system) and

also the cardiac baroreflex sensitivity in a non invasive way [3,4]. The baroreflex is a regulation loop of blood pressure with heart rate. For example it induces an increase of heart rate in response to a decrease of blood pressure. Both the vegetative system and the baroreflex are implied in the happening of rapid hypotension and syncope. Time frequency tools are developed in order to follow dynamic changes of the autonomic nervous system regulation [5,6]. They are particularly applicable to orthostatic tests.

The aim of this study is to propose a simple time frequency algorithm to monitor and analyze orthostatic tests.

This method was applied to LBNP in one cosmonaut. LBNP are performed by cosmonauts during their flight as a training exercise, in order to "simulate the gravity". This test limits the cardiovascular alterations induced by weightlessness [7].

II. METHODOLOGY

Subject:

One Russian cosmonaut was studied during a 189 days flight in the Mir station in 1999.

Orthostatic test:

LBNP (Lower Body Negative Pressure) test was performed 60 days (D-60) before the flight, The 7th (D+7), 27th (D+27), 97th (D+97), 163rd (D+163) day of the flight and 4 days after the landing (R+4). After a basal period, two levels of depression were applied during the LBNP: -25 mmHg and then -45 mmHg for 5 minutes each step. A slow transition over one minute was performed between the two levels of depression.

Acquisition of data:

During the LBNP test, beat to beat blood pressure was recorded continuously with a Portapres® (TNO, the Netherlands) by finger photoplethysmography. Also, RR interval (RRi), the time between two R waves, with a 1000 Hz ECG circuit.

Time frequency analysis:

Baroreflex sensitivity is expressed in $\text{ms}\cdot\text{mmHg}^{-1}$ and

corresponds to the changes in RRi that are caused by changes in systolic blood pressure (SPB). Analysis of the baroreflex could be performed in frequency domains with spectral and cross spectral analysis. The baroreflex is thus considered as an input (systolic blood pressure) – output (RR interval) system [8]. With cross spectral analysis of SBP and RRi we could calculate the gain in transfer function between changes in SBP and RRi:

$$Gain = \sum_{f_1 \leq f \leq f_2} \sqrt{g^2(f)} \times \sqrt{\frac{S_{RRi(f)}}{S_{SBP(f)}}}$$

g^2 : squared coherence between RRi and SBP
 S_{RRi} : spectral power of RRi variations
 S_{SBP} : spectral power of SBP variations.

This gain evaluates the sensitivity of the baroreflex loop. This index is usually calculated into specific frequency bands, only for the frequency where the squared coherence is $> 0,5$.

This gain is usually computed in Low Frequency - LF (0.04-0.15 Hz) and High Frequency - HF (0.15-0.4 Hz) bands. There is no consensus on which frequency band is better to use. For some authors, the LF band is more specific for the baroreflex, for other authors HF variations in RRi and SBP also depend on the baroreflex and study

more specifically the influence of respiration on the baroreflex.

Computing this gain into the total frequency band - TOT (0.04-0.4 Hz) has thus been recently suggested. [9]

This gain was computed initially in stationary data. We adapted this algorithm to dynamic situations by using a 90 sec sliding window across the beat by beat SBP and RRi data.

The entire procedure is written with Matlab® (5.3 with signal processing toolbox – Mathworks®).

In practice:

- 1) The RRi and SBP series are preprocessed for eliminating abnormal values.
- 2) The two series are interpolated at 4 Hz (beta spline interpolation),
- 3) Sliding segments of 90 seconds are determined across all the data with a 70 second overlap,
- 4) A linear detrend is applied to each segment,
- 5) Estimates of Power Spectral Density for SBP and RRi using Welch's averaged periodogram method is performed on each segment,
- 6) For each segment the alpha gain is computed in LF, HF and TOT as described above.

In this study, we did not take in account the coherence as a cut off.

Fig1 is an example of the analysis of one LBNP session.

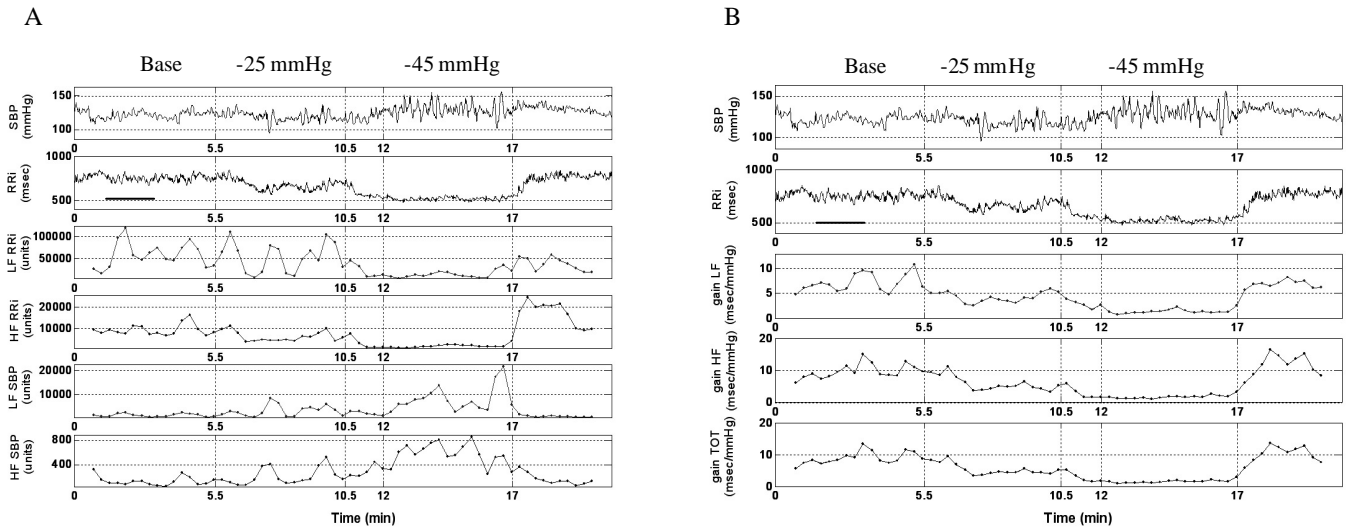


Fig. 1: Example of analysis of a LBNP test performed at D+27 (— size of the 90sec window)

- A) Beat by beat variations of SBP (systolic blood pressure) and RRi (RR interval) and spectral power in the low (LF) and high (HF) frequency band for those two series of data.
- B) Gain of the spontaneous baroreflex calculated on the low, high and total (TOT) frequency band calculated without squared coherence cut off.

III. RESULTS

The cosmonaut tolerated all the sessions of the LBNP and did not experience hypotension. Fig.2 represents the evolution of the baroreflex sensitivity calculated by the gain in the TOT frequency band with squared coherence cut off.

LBNP test induced a decrease of baroreflex sensitivity indexes (Fig. 2) as already reported. [10]. At the highest level of LBNP, weightlessness exposure induced decrease in the baroreflex sensitivity, marked at D+97 and D+163. For this cosmonaut the decrease was

evident only after long exposure to weightlessness, but seemed not evident at D+7. This impairment of baroreflex remained at R+4.

Calculating the baroreflex sensitivity in the other frequency bands has shown similar evolution during LBNP.

The use of a squared coherence cut off for the computation of the gain gave similar results also, but in some segments, because of low coherence, this gain could not be calculated.

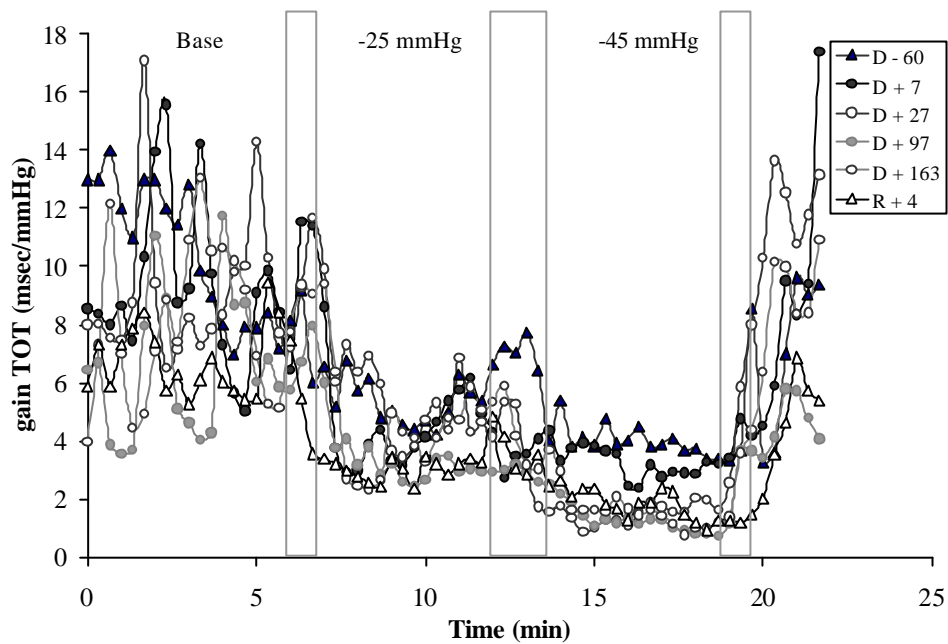


Fig. 2: Evolution of the baroreflex sensitivity during LBNP sessions in 1 cosmonaut before flight (D – 60) during flight (D+7, D+97, D+163) and after flight (R+4). The baroreflex sensitivity was calculated by the gain in the frequency band TOT. Squared coherence was not taken in account as a cut off.

IV. DISCUSSION

The method

This method allows following the gain of the transfer function between SBP and RRi during a dynamic test. It could be performed in real time during the test, with a few seconds delay.

This gain reflects the spontaneous baroreflex sensitivity as the baroreflex is considered as an input – output system.

Many parameters have to be chosen, especially the frequency band and the use of a cut off frequency. The TOT frequency band has the advantage to take in account the entire frequency band where the baroreflex

could operate. In a time-frequency analysis, the use of a large frequency band permits a higher resolution in time. For the measurement of gain of the baroreflex, a cut off frequency has been used to take in account only frequency with strong linear links between SBP and RRi. Nevertheless this cut off is arbitrary. We propose not to use this coherence as a cut of, because the coherence already acts as a weighting function for calculation of the gain of the baroreflex. The size of the sliding window is fixed empirically at 90 sec (=360 points) as a good compromise between spectral and temporal resolution.

The results

The decrease of baroreflex sensitivity during LBNP has already been reported. It might be the consequence of the decrease in circulating blood volume induced by LBNP. Weightlessness exposure induces also a decrease in the baroreflex sensitivity, but was evident for this cosmonaut only after long exposure to weightlessness. Neurovegetative alteration (at least functional) could be responsible for this baroreflex alteration.

V. CONCLUSION

This method is well adapted to study the baroreflex sensitivity in dynamic situations such as orthostatic tests. It could be performed in real time during the test.

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Following cardiovascular regulation during orthostatic tests could help to understand acute hypotension and syncope. Further studies, especially during non tolerated tests, are necessary to evaluate this method as a predicting tool of syncope.

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