NONLINEAR HEART RATE VARIABILITY ANALYSIS OF ASTRONAUTS BEFORE AND AFTER SPACEFLIGHT BY MEANS OF HOLTER RECORDINGS.

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ABSTRACT

Having Holter recordings of 8 astronauts before and after spaceflight, nonlinear HRV methods were applied to study the dynamics in cardiovascular regulation. The goal is to examine how the cardiovascular system is influenced by microgravity. The significant differences present some days after returning were disappeared after one month.

1. INTRODUCTION

Even after more than 600 people who have been in microgravity environment, it is still not clear how this influences the human body and more specific the cardiovascular system. Orthostatic intolerance and postural tachycardia indicate a change in the autonomic nervous system (ANS) and therefore the cardiovascular control. The ANS consists of a sympathetic and parasympathetic branch, always interacting each other. While the sympathetic network increases heart rate, the parasympathetic or vagal pathways cause a decrease of the heart rhythm.

Heart rate variability (HRV) has proven to be a good noninvasive tool to address the modulation by the ANS [1] and therefore HRV parameters are used to study the changes in cardiovascular control induced by microgravity. Not only standard HRV analysis will be used, but especially many nonlinear parameters since it has been shown that the ANS control underlies the nonlinearity and the possible chaos of normal HRV [2]. Nonlinear HRV methods were rarely applied on ECG data of astronauts because of the need of long term recordings while most studies only had 5 minute measurements. However, nonlinear parameters give additional information about the nonlinear dynamics in the cardiovascular system which can not be reflected by standard HRV analysis. Moreover, it enables us to examine the time evolution separately during day and night, as well as the day-night differences.

2. METHODS

2.1 Data.

24h-recordings of 8 astronauts were used of which five who have been in space for long duration missions and three who did short-term assignments. ECG is measured one month before launch (L-30), some days after returning (R+5) and one month after returning to earth (R+30).

2.2 Analysis

First, some basic filtering and preprocessing was applied to correct for missing and ectopic beats. Linear HRV parameters were obtained in agreement with the standards of measurement, proposed by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [2]. Mean and standard deviation (SD) of the tachogram, the square root of the mean of the sum of the squares of differences between consecutive RR intervals (rMSSD) and the percentage of intervals that vary more than 50 ms from the previous interval (pNN50) were calculated in the time domain. After resampling the tachogram at 2 Hz, the power spectral density (PSD) was computed by using the Welch method. In the frequency domain, low frequency power (LF: 0.04 – 0.15 Hz), high frequency power (HF: 0.16 – 0.40 Hz) and total power (0.01 – 1.00 Hz), as well as the ratio of low over high frequency power (LF/HF), were calculated. In addition, the power can be expressed in absolute values (ms^2) or in normalized units (n.u.).

Nonlinear HRV parameters do not describe the amount of modulation as such, but are able to describe the scaling and complexity properties of the signal. Often used parameters which study the scaling of the system are 1/f slope, fractal dimension (FD) and detrended fluctuation analysis (DFA α_1 & α_2). In order to address the complexity of the signals, the correlation dimension (CD), maximal Lyapunov exponents (LE), sample entropy (SampEn) and Noise Limit (NL) are calculated. An overview of these methods is recently given by Aubert et al. [4].

Statistical analysis was done by the nonparametric Wilcoxon Signed Rank test to compare, for each HRV parameter, pairwise between the different time moments. $P < 0.05$ was considered statistically significant. The Pearson Correlation Coefficient 'r' was calculated to examine the similarity between the HRV parameters.

3. RESULTS & DISCUSSION

All statistical parameters showed a significant or nearly significant decrease at R+5 which was more pronounced during day than night. On the contrary, mean RR showed no evolution at all as shown in Fig. 1. All effects seemed to be disappeared 30 days after return.

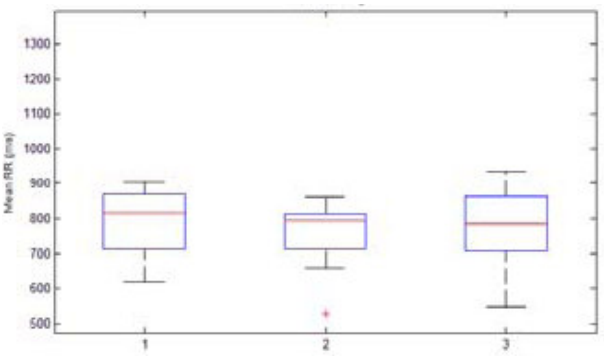

Fig. 1. Boxplot for mean RR intervals during pre flight (1), early post flight (2) and late post flight (3) at daytime.

As this study focuses on the nonlinear HRV parameters, these results are displayed in Table 1. Compared to the linear parameters, the nonlinear ones were more diverse. All, except for DFA α_1 and FD, showed different values between day and night recordings. During daytime, there was only a significant decrease from pre to post flight for FD ($p=0.036$), SampEn ($p=0.012$) and LE($p=0.012$) and a significant increase of CD ($p=0.025$). For night recordings a small increase in DFA α_1 ($p=0.028$) was noted as well as a nearly significant decrease of SampEn ($p=0.063$) and LE ($p=0.091$). At R+30, none of these parameters were still significant different from the corresponding one at L-30, indicating that the dynamic behaviour of the cardiovascular control is completely recovered one month after returning.

Based on the correlation coefficients, similarity between the different parameters was studied. A lot of significant large r values were found, but here, only the most significant results ($r>0.5$ and $p<0.001$) related with nonlinear HRV parameters will be considered. LE and SampEn were strongly correlated with pNN50, rMSSD and HF ($0.718<r<0.973$), all expressing parasympathetic modulation, while DFA α_1 was clearly related with LF/HF and LF(n.u.) ($0.781<r<0.881$), reflecting the sympathovagal balance. Other strong correlations were found between CD & LE, SampEn & 1/f and DFA $\alpha 2$ & 1/f with r values of respectively -0.503, -0.512 and -0.774.

Table 1. Average values for all described nonlinear HRV parameters during pre flight(L-30), early post flight (R+5) and late post flight (R+30), both for day and night time.

	Day			Night		
	L-30	R+5	R+30	L-30	R+5	R+30
1/f	-0.77	-0.86	-0.76	-1.59	-1.57	-1.34
DFA α_1	1.38	1.38	1.35	1.25	1.40	1.26
DFA α_2	0.96	0.96	0.93	1.04	1.09	1.06
FD	1.77	1.72	1.73	1.75	1.74	1.75
CD	2.75	2.92	2.91	2.67	2.71	2.69
SampEn	2.89	2.55	2.83	3.39	3.05	3.18
Max LE	0.45	0.34	0.39	0.58	0.40	0.58
NL	6.01	6.34	3.85	10.40	9.34	6.48

In general, the nonlinear parameters did not show any consistent alignment or time evolution. Therefore one has to remark that the different nonlinear parameters address different aspects of the scaling and complexity of the signal and should be evaluated independently.

4. CONCLUSION

This study examined the evolutions of different aspects of the cardiovascular regulation before and after a stay in a microgravity environment by using nonlinear HRV parameters. Some showed significant differences short after returning to Earth, but the dynamic behaviour of the cardiovascular control is completely recovered after one month. However they did not show any consistent alignment or time evolution, many of them seemed useful in the study of the physiological changes caused by microgravity. They can be a supplement for parameters who express vagal modulation or the sympathovagal balance. In order to use them separately more research and standardization is needed.

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