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Assessment of individual adaptation to microgravity during long term space flight based on stepwise discriminant analysis of heart rate variability parameters ☆

Roman M. Baevsky [a], Anna G. Chernikova [a,*], Irina I. Funtova [a], Jens Tank [b]

[a] RF SRC, Institute of Biomedical Problems of the RAS, 123007, Choroshevskoe Shossee, 76a, Moscow, Russia
[b] Hannover Medical School, Institute of Clinical Pharmacology, Hannover, Germany

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ABSTRACT

Optimization of the cardiovascular system under conditions of long term space flight is provided by individual changes of autonomic cardiovascular control. Heart rate variability (HRV) analysis is an easy to use method under these extreme conditions. We tested the hypothesis that individual HRV analysis provides important information for crew health monitoring. HRV data from 14 Russian cosmonauts measured during long term space flights are presented (two times before and after flight, monthly in flight). HRV characteristics in the time and in the frequency domain were calculated. Predefined discriminant function equations obtained in reference groups ($L1 = -0.112*HR - 1.006*SI - 0.047*pNN50 - 0.086*HF$; $L2 = 0.140*HR - 0.165*SI - 1.293*pNN50 + 0.623*HF$) were used to define four functional states. (1) Physiological normal, (2) prenosological, (3) premorbid and (4) pathological. Geometric mean values for the ISS cosmonauts based on L1 and L2 remained within normal ranges. A shift from the physiological normal state to the prenosological functional state during space flight was detected. The functional state assessed by HRV improved during space flight if compared to pre-flight and early post-flight functional states. Analysis of individual cosmonauts showed distinct patterns depending on the pre-flight functional state. Using the developed classification a transition process from the state of physiological normal into a prenosological state or premorbid state during different stages of space flight can be detected for individual Russian cosmonauts. Our approach to an estimation of HR regulatory pattern can be useful for prognostic purposes.

1. Introduction

Among psychological strain, extreme physical loads, unusual noise and others, space flight is characterized by the specific factor of microgravity. Numerous investigations during short and long term space missions showed that functional parameters of the cardiovascular and respiratory systems remain within normal ranges typical for life at 1g. However, during microgravity regulatory mechanisms control and adjust physiological functions of different end organs individually in each astronaut leading to adaptation and fairly big changes may occur in the regulatory systems. In other words, homeostasis maintenance "costs" have to be paid.

Changes of blood pressure (BP) and heart rate (HR) seen in cosmonauts during space flight may be relatively small if compared to patients with cardiovascular diseases. Nevertheless, these small changes are the result of compensatory changes of the regulatory systems and measurements of cardiovascular and respiratory control contain important information for crew health control.

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* Corresponding author. Tel.: +7 499 193 6244.
E-mail address: anna.imbp@mail.ru (A.G. Chernikova).

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Consequently, a concept of health [1] was developed in Russia from the very beginning of space medicine. The concept is focused on practical issues of health control during space flight including the system of medical monitoring and predicting deviations in the functional state of crew members. Therefore, the prediction of probable changes in crew health state is one of the key objectives of medical monitoring in space flight. Preference was given to the method of heart rate variability (HRV) analysis in order to keep the measurements simple and reliable during manned space flights [2–5].

Numerous prospective clinical studies showed that there is a cardiovascular continuum of complex changes going on and different risk factors contribute to cardiovascular diseases preceding the end organ damage. HRV and blood pressure variability analysis support this hypothesis and early changes in the regulatory systems can be detected, which are independent predictors for clinical outcome in patients [6–8]. A prenosological approach was developed in Russia, which implies recognition of transition states between health and disease based on data from space medicine [9–11] and from large epidemiological studies. Four classes or functional states were described based on HRV analysis parameters. The classification system was originally developed in space medicine but is now widely used in practical medicine in Russia [1]. The present paper illustrates the use of the HRV classification system to assess small changes of the functional state of Russian cosmonauts onboard the ISS during long term space flight.

2. Methods

2.1. Subjects

All HRV data were obtained from ECG recordings (sample rate 1000 Hz) in 14 Russian crew members of the International Space Station (ISS, men, $n=14$, age from 35 to 54 years) during the last flight months (5 and 6 month) and analyzed using the HRV classification system. The classification system was developed from ECG data in reference group -192 healthy subjects (visitors of health center, men and women, $n=192$, age from 38 to 63 years). The classification system was further tested in Russian cosmonauts during space flights onboard the MIR station (men, $n=34$, age range 35–55 years), in healthy subjects during a 120-day head down tilt bedrest study (men, $n=6$, age range 28–36 years), and in healthy subjects studied during 8-month isolation (men, $n=4$, age range 37–48 years). Measurements in all groups were carried out under resting conditions. All subjects signed a written consent form. The study protocol was approved by the institutional ethical commission.

2.2. HRV analysis

Analysis of HRV parameters was performed according to the standards of the European Society of Cardiologists and North-American Society of Electrostimulation and Electrophysiology [12]. HRV characteristics in the time domain (SD, standard deviation; CV, coefficient of variation; rmssd, root mean square of successive differences; pNN50, number of RR-interval pairs differing by more than 50 ms, SI, triangular index or stress index for characterization of the histogram) and in the frequency domain (TP, total spectral power of HRV; VLF, HRV power in the very low frequency range; LF, HRV power in the low frequency range; and HF, HRV power in the high frequency range) were calculated as described elsewhere [13].

3. Results

3.1. Stepwise discriminant analysis

A classification system based on HRV analysis was developed using data from well characterized 192 volunteers (women $n=51$, age range 38–62 years; men, $n=141$, age range 39–63 years, reference group). This reference group contained patients and healthy subjects. The most informative parameters for sufficiently high accuracy of recognizing specific functional states were mean heart rate (HR), the triangular histogram index (SI), pNN50 and the HF spectral power. The standard form of discriminant function equations for the first two canonic variables (L1 and L2) is given below

$$L1 = -0.112*HR - 1.006*SI - 0.047*pNN50 - 0.086*HF;$$
$$L2 = 0.140*HR - 0.165*SI - 1.293*pNN50 + 0.623*HF.$$

Canonic variables were calculated from absolute values of HRV parameters. Analysis of standardized coefficients in these equations shows that SI has the highest weight in the first equation, while pNN50 and HF have the highest weight in the second equation.

Comparison of the physiological normal state with the other functional states was made by analysis of reference data arrays obtained from mathematical modeling and incremental discriminant analysis to deduce the decision rule.

Parameters L1 and L2 were referred to as coordinates of the phase plane configuring the space of functional states as shown in Fig. 1. The functional states are situated on the phase plane in such a way that the physiological normal state is characterized by positive L1 and negative L2 values. The center is in the lower right quadrant of the phase plane. The remaining functional states are located in the other quadrants, i.e. prenosological state in the upper right, premorbid state – in the upper left and pathological state – in the lower left quadrant.

The averaged L1 and L2 values for the different groups are shown as geometric means (Fig. 1). The geometric means of all study groups were within the normal range. However, a shift towards the prenosological area was detected during the bedrest study as well as during isolation and long term space flight.

HRV data from 14 Russian cosmonauts obtained before, each month during 5–6 month in space, and after space flight were analyzed and the canonical variables were calculated. Fig. 2 illustrates the geometric means of the 14 cosmonauts.

Compared to the Russian cosmonauts measured onboard the MIR station also the mean values for the ISS cosmonauts were within normal ranges before flight and early during flight. Nevertheless, a trend towards a shift from the lower right to the upper right was present