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Heart rate dynamics during long-term space flight: Report on Mir cosmonauts

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We report the first observations of a joint Russian-American collaborative study initiated in 1990 to obtain and analyze continuous electrocardiographic (ECG) data from cosmonauts aboard the Mir Space Station. The objective of the study was to test the hypothesis that the dynamics of heart rate variability change progressively during prolonged exposure to weightlessness. Short-term exposure to microgravity may induce marked physiologic alterations associated with the shift of fluid between parts of the body, neuroautonomic alterations, and deconditioning.[1] Therefore prolonged space flight would be anticipated to have potentially profound effects on cardiovascular control mechanisms, as determined, for example, by changes in beat-to-beat heart rate fluctuations.

Serial Holter monitor recordings for up to 24 hrs were obtained on six male cosmonauts ages 38 to 50 yrs during Mir missions 6, 7, and 8 (flight lengths 179, 131, and 175 days, respectively). ECG waveforms digitized at 120 Hz (FT 2000 System, Spacelabs, Inc, Redmond, Wash.), were classified automatically as normal or not with a computer program, and the beat classifications were visually edited. Recordings were obtained during routine activity preflight, early in-flight, midflight, late flight, and beginning 40 to 60 min postflight. The in-flight daily activity approximated regular activities on earth as much as possible. The crews maintained a 24 hr daily schedule with alternating sleep-wake and work cycles. The daily routine also included time (up to 2 hr) for exercise on a treadmill or bicycle ergometer. For up to 8 hours a day the cosmonauts wore "Penguin-3 suits" that incorporate joint tethers designed to provide additional axial loading to the musculoskeletal system but which did not affect the ECG recordings. No attempt was made to control respiration or postural variability during these recordings.

A summary of conventional heart rate statistics for the cosmonauts is given in Fig. 1. The mean heart rates did not vary significantly over the course of the missions compared to preflight rates. The highest rates were noted immediately after each flight. An even more prominent postflight increase in heart rate has been previously reported after shorter (4 to 5 days) missions.[2] Beginning early in-flight, heart rate variability decreased significantly. Spectral analysis showed that this decreased variability was associated with a reduction in relatively low frequency (0.01 to 0.15 Hz) fluctuations. High-frequency components of heart rate variability (0.15 to 0.5 Hz) were not significantly altered for the group. Of interest, sometimes marked interindividual variations in heart rate dynamics were observed over the course of the missions. For example, on one of the flights, one cosmonaut showed a decline in respiratory sinus arrhythmia by the end of the mission, and the other crew member showed an increase at the same postflight time (Fig. 2).

To quantitate changes in the longer-range correlation properties of heart rate dynamics, we computed the slopes of the graphs obtained by plotting heart rate spectra on double-log axes for continuous 8 hour periods. For healthy subjects under physiologic conditions, such log power versus log frequency plots typically show a linear inverse relationship with a slope of close to −1. A variety of pathologic conditions, as well as aging, may shift the slope of this regression line.[3] We found no significant changes in this spectral scaling exponent over the course of these missions compared to preflight values (−0.98 ± 0.08). We also computed the approximate entropy (ApEn) of the heart rate

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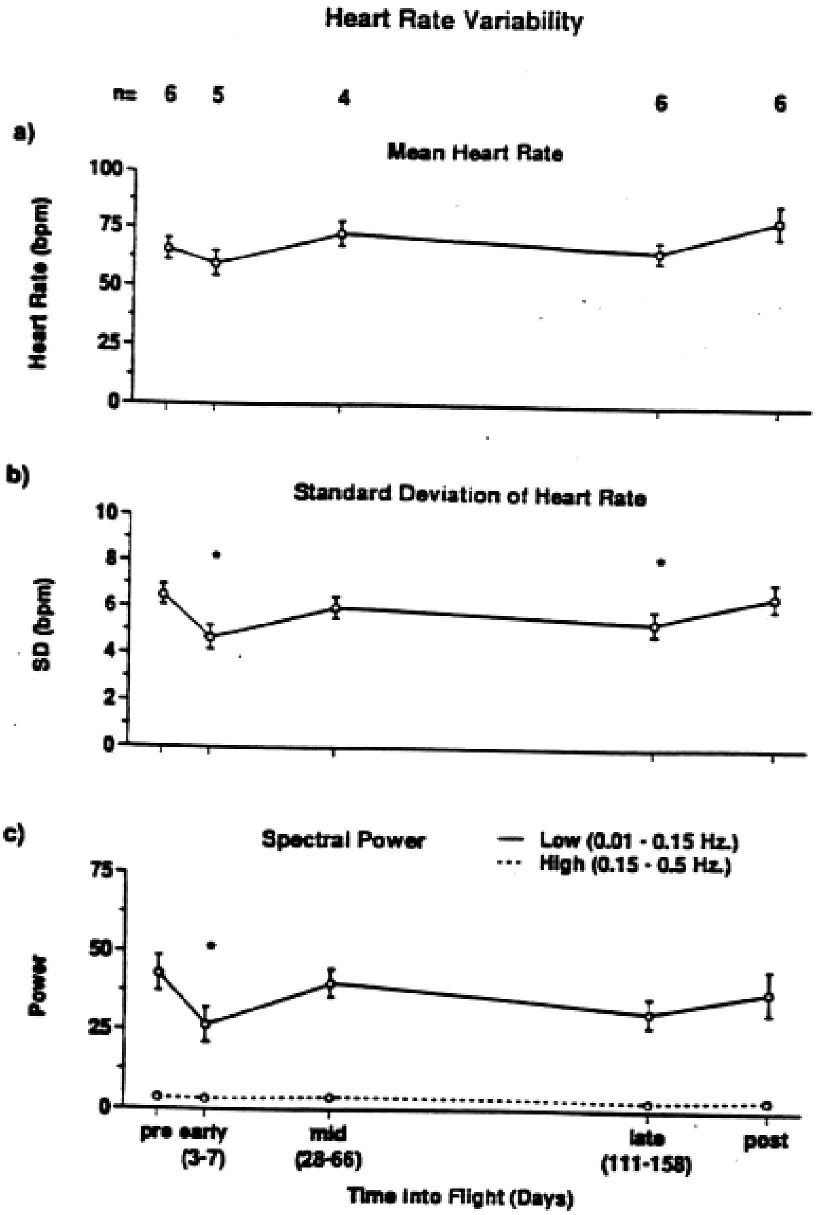

Fig. 1. Changes in **(a)** mean heart rate **(b)** and SD of absolute heart rate, and **(c)** spectral power (normalized units) are plotted over course of flight, preflight *(pre)* and immediately post flight *(post)*. Data were obtained by averaging consecutive 15 min epochs for subjects *(n)* having at least 15 hrs of adequate Holter monitoring data. Data for all graphs are shown as mean ± SEM *(error bars)*. ***Asterisk*** indicates statistically significant difference vs preflight control values. Bootstrap-based statistical procedure was used to estimate 5% and 95% confidence limits. Differences were considered significant if there was no overlap between confidence limits (for mean heart rate, only difference between early flight and post flight was significant.)

time series.[4] This statistic, derived from nonlinear dynamics ("chaos theory"), provides a measure of the degree of the overall "complexity" of a time series. More complex variability (*i.e.*, less regularity or predictability) produces higher values of ApEn. A variety of pathologic conditions and aging,[4] may decrease the complexity of heart rate variability. Heart rate ApEn was not significantly changed throughout the course of these flights. Furthermore, no clinically important arrhythmias were noted.

In summary, we find that a variety of indexes of short-range and longer range heart rate variability are surprisingly stable despite the stresses associated with prolonged microgravity exposure. Subtle changes in relatively low heart-rate frequency power may be related to altered blood volume or baroreflex function.[5] Overall, these findings are evidence for the preserved integrity of the feedback systems regulating heart rate dynamics. The vigorous in-flight exercise regimens and use of Penguin-3 suits, designed to counter the effects of microgravity and deconditioning, may have influenced neuroautonomic responsiveness, although controlled observations were not available. However, potentially important pathophysiologic alterations cannot be excluded by the present observations. Additional long-term monitoring of cardiovascular dynamics is par-

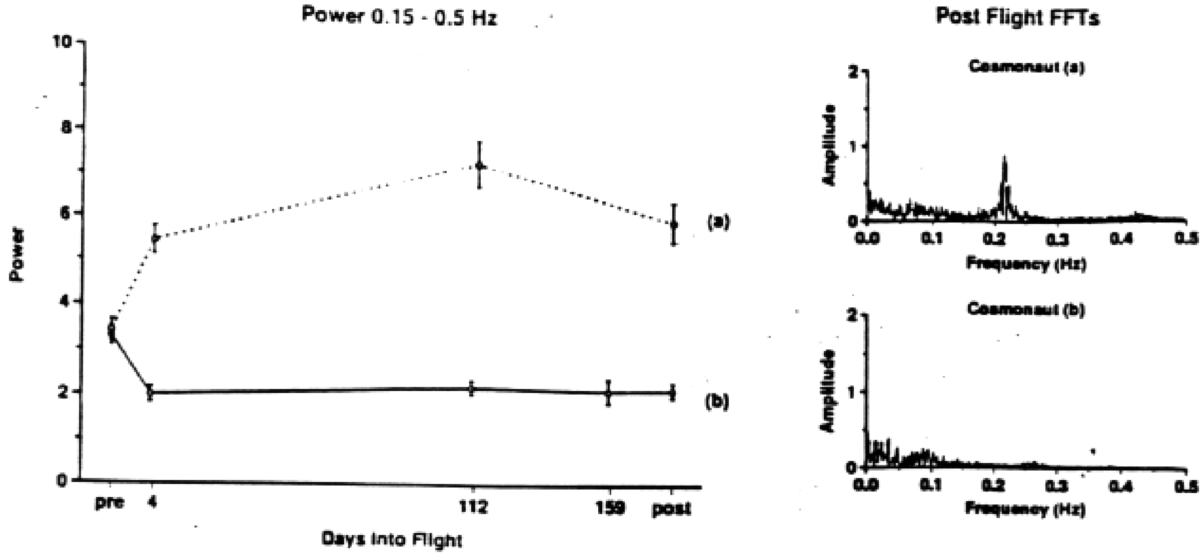

Fig. 2. Two cosmonauts on same mission showed marked interindividual differences in heart rate dynamics. One subject (a) showed apparent increase in higher frequencies (0.15 to 0.50 Hz) that correlate with respiratory sinus arrhythmia, and other (b) showed decrease in this band. *Right panels* show representative heart rate fast Fourier transform plots *(FFTs)* obtained on postflight data illustrating differences in high-frequency fluctuations.

ticularly needed during episodes of space sickness, with various exercise protocols, during metronomic breathing, and with exposure to lower body negative pressure and other orthostatic challenges, postural shifts, and selected pharmacologic agents.[6] Investigations are also needed to determine whether interindividual differences in heart rate dynamics (Fig. 2) can be used to predict successful adaptation to flight or post-flight deconditioning. International collaborative investigations aimed at further testing the stability of physiologic control mechanisms during long-duration space flight will be helpful in preparing for future space station development.

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