Sympatho-vagal modulation of cardiovascular functions of aerobic and resistance trained individuals in simulated microgravity

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Abstract

Postflight orthostatic intolerance is a major problem for the astronauts after they return from spaceflight. Cardiovascular system (CVS) gets adapted quickly to microgravity condition and new equilibrium is established for proper functioning of the CVS system in the altered environment. Once the astronaut returns to the terrestrial environment, impairment in CVS and other systems of the body under 1G condition of the earth make them susceptible for orthostatic intolerance. The postflight orthostatic intolerance also depends on the physical fitness status of the individual. The objective of the present study was to assess and compare orthostatic tolerance of a group of endurance trained and resistance trained Army individuals following simulated microgravity condition. The simulation of physiological effect of microgravity was created by head-down bed rest. The heart rate variability (HRV) and blood pressure (BP) response of endurance and resistance trained individuals during orthostatic stress was assessed in head up tilt test before and after head down bed rest. The results of the analysis of HRV and BP indicated that there was significant increase in sympathetic input and non-significant change in parasympathetic input during orthostatic stress in endurance trained individuals and lower HF spectral power and attenuated increase in LF spectral power during orthostatic stress in resistance trained individuals.

Key words: orthostatic stress, head down bed rest, endurance training, resistance training, microgravity simulation, cardiovascular system

Introduction

Exposure to microgravity condition poses many challenges to human body and especially after return from the spaceflight; the astronauts suffer from postflight orthostatic intolerance. The intolerance is thought to be the results of multitude of changes in the cardiovascular to neurovestibular system in microgravity condition. The space flight induced reduction in plasma volume, orthostatic tolerance, aerobic power, concomitant with alterations of autonomic regulation of cardiovascular function, remains a problem for space travellers (1). Post-flight orthostatic intolerance is a major problem that destabilizes the cardiovascular functioning on the gravity environment of the earth after astronauts return from space flight and compromise their capability to withstand the orthostatic stress. Study has reported that about 30% of astronauts after short duration space flights (2) and 80% of astronauts after long duration space flights become pre-syncopal during tilt or stand test (3-4). The level of Physical fitness of the individual and its relation to susceptibility to post space flight orthostatic intolerance is still an area of debate. Conflicting reports have emerged from various studies regarding the exact physiological effects of different types of exercise training on the phenomenon of orthostatic intolerance. Whether endurance exercise training induces orthostatic intolerance and alters blood pressure regulation during orthostasis have been debated since the early 1970s (5). Endurance trained subjects were found to be more susceptible to orthostatic hypotension than untrained subjects (6-9). On the contrary, McCarthy et al suggested that intense resistance exercise training for 12 weeks may increase blood volume but did not consistently improve orthostatic tolerance in sedentary man (10).

Of late, heart rate variability (HRV) analysis has emerged as an important investigation tool for assessing cardiovascular function. By measuring various descriptors of the heart rate variability, it has been possible to understand the impact of autonomic neural influence on functioning of heart and cardiovascular system. In linear methods, time domain and frequency domain methods are used to analyse the result of the heart rate variability. It is well documented in the literatures that physical training is associated with reduction in sympathetic and increase in parasympathetic drive to the heart. HRV has been used during and after exposure to actual microgravity or its simulation on the earth (11-13).

Studies are scanty where HRV and blood pressure (BP) have been measured during orthostatic stress after microgravity simulation of short duration in endurance trained (E) and resistance trained (R) individuals. The effect of chronic exercise training on sympatho-vagal modulation of cardiovascular function is different amongst E and R trained individuals. The present study was conducted with an aim to assess modulation of autonomic cardiovascular function during orthostasis in E and R trained athletes by using analysis of heart rate variability (HRV) and BP after exposure to six hours of simulated microgravity condition. This can help to select right individual with different training background for human space flight.

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Material and Methods

13 endurance trained (E) and 12 resistance trained (R) non-smokers and non-alcoholic healthy male volunteers of an Army Unit of Bangalore from a population of endurance and resistance trained players were selected randomly for the present study. Age, height and body weight of the E and R trained participants were 21.5±3.45 years, 170.0±5.08 cm, 60.7±4.20 kg and 22.4±1.68 years, 171.0±6.46 cm and 80.7±9.45 kg respectively. E trained volunteers were chosen from swimmers and cross country runners and R trained subjects were selected from body builders and weight lifters. The participants were highly trained athletes and had undergone training for last 9-10 years. The detailed clinical history of each participant was recorded and was clinically examined to rule out any disease. After ascertaining their health status, they were recruited in the study. They were explained in detail the possible outcome and adverse consequences of head down bed rest (HDBR) for six hours followed by head up tilt test (HUT). Ethical committee of the Institute of Aerospace Medicine, Bangalore approved the test protocol of the study. Informed consent was obtained from each participant before the study.

Each participant reported to the Department of Physiology at 0800 h. Their baseline physiological parameters like heart rate (HR), blood pressure (BP), arterial oxygen saturation (SPO_2), electrocardiogram (ECG) were recorded for 10 min. After recording of baseline (BL) parameters, the individual was made to lie on an automated tilt table with a footboard support. The individual was fastened securely with the table by 3 wide straps to prevent falling from the table, in case he loses consciousness during the tilt. The table was then tilted to head up position at an angle of 70° for 20 min. The physiological parameters of the individual were monitored continuously during head up tilt test (HUTT1). The table was then tilted back to horizontal position and after about 10 min of rest at supine posture; the table was tilted at head down position at an angle of -6° from the horizontal level. Condom catheter was used for disposal of urine during HDBR. They were given a fixed amount of fluid during the test. After 6 h of HDBR, the participant was brought back to supine position and immediately tilted to head up position again for 20 min to check their orthostatic response after HDBR. Physiological parameters of the individual were monitored during head up tilt test (HUTT2) after HDBR.

Akron multipurpose automatic tilt table (Model 9622, Huntleigh Akron, UK) was used for HUTT. The automated tilt table is an electrically operated tilt table with the dimensions of 6.5x3 feet and 1.5 meters height. It is adequately padded with a 1.5 inches thick rubber mattress.

Heart rate was recorded by single lead electrocardiography by a physiological data recorder Procomp Infiniti 5.0 (Thought Technology, Montreal, Canada). Three electrodes were placed on surface of the subjects' chest, one at just below the right shoulder; other at just below the left shoulder and a third electrode near the umbilicus. The skin where electrodes to be placed was removed of hair and cleaned with spirit. Negative and ground terminal of the ECG sensor were connected to right and left electrode respectively. Positive terminal of the ECG sensor was connected to the electrode near the Umbilicus. ECG was recorded for 10 min at baseline supine, 20 min of HUTT before and after HDBR and last 30 min of 6 h of HDBR.

Kubios HRV analysis software, version 2.1, Finland, was used to analyze the ECG data for measurement of various time domain and frequency domain indices of HRV. Different indices of HRV were measured as per the guidelines of the Task Force of European Society of Cardiology and the North American Society of Pacing and Electrophysiology (14).

For time domain analysis, peak R wave was detected from ECG wave and R-R interval time series was plotted after rejecting the artefacts. ECG data was then interpolated in order to sample the data equidistantly for frequency domain analysis. Power spectral density (PSD) analysis is the most common method of computing frequency domain parameters. PSD estimation provides the basic information of how the power of the signal (i.e., its variability) distributes as a function of frequency. This estimation can be made by two different types of methods: non-parametric and parametric. The non-parametric method is computationally simpler and the results obtained are very similar to the parametric results. Fast Fourier Transform (FFT) computation, based on Welch's periodogram (15), is the basis of the non-parametric PSD analysis.

Various time domain indices of HRV computed from ECG recording included mean HR, standard deviation of HR (STD HR), standard deviation of N-to-N intervals or RR intervals (SDNN in ms), root mean square of successive differences between adjacent NNs (RMSSD in ms).

Various frequency domain indices of HRV computed from ECG signal after transforming the ECG signal by Fast Fourier Transformation (FFT) were very low frequency power (VLF) (ms^2) (0.00-0.04 Hz), LF power n.u.(Power of low frequency in normalized unit) (0.04-0.15 Hz), HF power n.u. (Power of high frequency expressed in normalized unit)(0.15-0.40 hz) and LF/HF (Ratio between LF and HF band powers).

Arterial blood pressure was recorded by arterial tonomter, Finometer Midi (Finapres Medical System, Netherland) on a beat to beat basis. Continuous non-invasive measurement of BP was measured by using finger cuff technology. An appropriate sized finger cuff was wrapped around 2nd phalanx of the middle finger of left hand. The method of recording continuous blood pressure was based on the volume-clamp technique discovered by the Czech physiologist Jan Peňáz (16-18). The diameter of a finger artery under a cuff was "clamped" i.e. kept at a constant diameter in the presence of the changes in arterial pressure during each heartbeat. Changes in diameter were measured by means of an infrared photo-plethysmograph built into the finger cuff. The finger cuff kept the diameter of the underlying arteries constant by dynamically applying a counter-pressure throughout the cardiac cycle. When, for instance, during systole an increase in arterial volume is detected by the plethysmograph, the cuff pressure is immediately increased by a rapid pressure servo-controller system to prevent the volume changes. Arterial blood pressure was reconstructed from the recorded finger pressure using the Beatscope software of Finapres arterial tonometer. Various scientific studies have revealed that the finger arterial pressure measured by Finapres correlated well with the brachial arterial pressure in clinical as well as experimental settings (19-20).

Statistical Analysis

Statistical software Statistica 6.0 was used to analyze the data. Data was first checked for the normality by Shapiro Wilks 'W' statistic. Two factors repeated measure ANOVA was carried out for comparison of different HRV indices between E and R trained individuals during HUTT before and after HDBR. Two factors were type of training (having 02 levels namely endurance training or resistance training) and the conditions of testing (six levels i.e. baseline (BL), first 5 min of HUTT1, 6-10min of HUTT1, HDBR, first 5 min of HUTT2 and 6-10th min of HUTT2). Single factor repeated measure ANOVA was carried out for comparing values intra group. After significant outcome from the ANOVA, the individual comparison was made by using Tukey HSD test. The level of significance was kept at $p<0.05$.

Results

The time domain and frequency domain indices of HRV at baseline condition, during first 5 min & 6-10th min of head up tilt test before and after head down tilt are shown in table 1. Mean HR increased significantly during HUTT from baseline in E trained at pre-HDBR ($p<0.001$) and at post-HDBR ($p<0.001$) and mean HR increase in R trained was not significant. No significant difference was observed in RMSSD and VLF parameters during HUTT as compared to baseline either in E trained or R trained personnel. Also, inter group comparison did not show any significant difference. LF n.u. increased significantly during HUTT from baseline at pre-HDBR ($p<0.05$) and at post-HDBR ($p<0.01$) in E group and did not show any significant difference in R group. HF n.u. decreased significantly during HUTT after HDBR ($p<0.01$ during first 5 min of tilt and $p<0.05$ during 6th-10th min of tilt) and non-significantly before HDBR in E group. HF n.u. did not show any significant variation in R group. LF/HF ratio was significantly higher during HUTT from baseline after HDBR ($p<0.001$ during first 5 min and $p<0.05$ during 6th-10th min) in E group. No significant variation was observed in R group.

Table 2 shows systolic (SBP), diastolic (DBP) and mean arterial pressure (MAP) data of E and R trained individuals at baseline, during HUTT before and after HDBR and during HDBR. SBP was significantly higher in R trained than E trained at all four conditions of testing. DBP was significantly higher during HUTT2 in R trained than E trained (($p<0.01$). MAP was significantly higher in R group during HUTT1 ($p<0.01$), HDBR ($p<0.01$) and HUTT2 (($p<0.01$). It was also observed that SBP did not increase during HUTT2 in E group from BL unlike R group where SBP increased significantly ($p<0.001$). No significant difference in DBP in E group across different conditions was observed. DBP increased significantly during HUTT2 in R group from BL ($p<0.001$). MAP increased significantly during HUTT2 in E group ($p<0.01$) and R group ($p<0.001$) from BL.

Discussion

The present study examined the orthostatic tolerance of endurance trained and resistance trained subjects during orthostatic stress before and after six hours of head down bed rest. It was observed that HR increase during HUTT was significant in both the groups before and after HDBR. But the increment of HR in E trained subject was of a greater magnitude than R trained subjects, though both groups had a similar resting supine HR before tilt. It was also observed that E group had a significantly higher HR during orthostatic stress test post-HDBR as compared to pre-HDBR. The R group did not show any variation in pre and post-HDBR HR during HUTT. HR increase during orthostatic stress depends on degree of sympathetic activation which in turn depends on many physiological factors like, degree of pooling of blood in lower limbs, venous return to the heart and degree of activation of baroreceptors in the heart in order to readjust the fall in blood pressure (21). Stimulation of baroreceptors in turn causes the augmented sympathetic neural discharge and attenuated vagal output to the heart. In final, HR is increased to maintain cardiac output and prevent fall in blood pressure.

Frequency domain analysis of heart rate variability revealed that a significant increase in low frequency wave (LF n.u.), a measure of sympathetic neural discharge, was observed in E group during pre-HDBR HUTT ($p<0.05$) as well as post-HDBR HUTT ($p<0.01$) (Table 1). This was not observed in R group. High frequency wave, a measure of vagal activity, was found to be significantly lower in E group than R group during post-HDBR HUTT ($p<0.01$ during first 5 min and $p<0.05$ during 6-10th min). LF/HF ratio increased from

1.67 (baseline) to 4.16 (first 5 min of HUTT) and 3.6 (6-10th min of HUTT) and again decreased to 1.45 (HDBR) in E trained individuals (Table 1). The ratio increased significantly from baseline at post-HDBR HUTT to 5.81 (first 5 min) and 4.89 (6-10th min). This was not observed in R trained individuals, they had an attenuated LF/HF ratio during post-HDBR HUTT. LF/HF ratio had a higher value during post-HDBR HUTT as compared to pre-HDBR HUTT in E trained people. This suggested that the cardiovascular control of E group was modulated via sympathetic nervous system during orthostatic stress post-HDBR than pre-HDBR. The similar sympathodominance was not observed in R trained people during post-HDBR HUTT. Scientific literatures in favour of shifting of autonomic balance towards increased sympathetic and decreased parasympathetic influence in regulating cardiovascular function after exposure to short-term simulated microgravity has been reported in human (22) as well as in animal model (23). Yang et al also reported that under hemodynamic stress during exposure to LBNP, when stroke volume reduced to a certain degree, the sympathetic activity increased to the maximum. The LF/HF ratio increased during LBNP (24). Migeotte et al studied the heart rate and HRV in four male subjects before, during, and after 16 days of spaceflight. They observed that heart rate was decreased during early in-flight (4 days after launch) from pre-flight supine and LF/HF ratio was similar to pre-flight supine values throughout microgravity (25). Brown et al measured the heart rate variability of healthy adult male non-smokers with no cardiovascular, respiratory and medical abnormalities in supine posture and during 80° head up tilt posture. They observed that LF n.u. increased from 31.85 at supine to 47.03 at tilt test and HF n.u. decreased from 67.85 to 50.50. LF/HF ratio increased significantly from 0.67 at spine posture to 1.79 at tilt (26). In the present study, the increase in LF n.u. from baseline to HUTT was found to be more in E group than R group either before or after HDBR. This suggests that enhanced sympathetic activity in E trained group during orthostatic stress as compared to their R trained counterparts. Though, decrease in HF n.u. in both E and R group during HUTT before and after HDBR was of similar magnitude, but absolute value of HF n.u. was lower in E trained than R trained individuals. This suggests that influence of vagal nerve on cardiac activity was more prevalent in R trained than E trained during orthostatic stress. This perhaps explains comparatively lower HR in R group during HUTT than E group. RMSSD, a time domain parameter of HRV, has been reported to be associated with vagus nerve mediated control of the heart rate (27). RMSSD decreased non-significantly during HUTT in E and R trained individuals, indicative of reduced vagal influence on the heart. Also, the reduction in RMSSD was found to be more in E trained than R trained. This perhaps explains the higher vagal dominance in R group. VLF in the power spectra of HRV has been suggested in the literature a major contributor of vagal influence (28). The non-significant increase in VLF at a higher proportion in R group than E group also supports the fact of higher vagal influence in R trained group during HUTT before and after HDBR. Relatively, attenuated increase in VLF during HUTT before HDBR and decrease in VLF after HDBR in E trained individuals supports the view point of higher increase in HR under orthostatic stress. During orthostatic stress R group was found to maintain a higher SBP, DBP and MAP than their R trained counterparts despite the fact of attenuated increase in LF spectral power in R trained individuals. Study has suggested that alteration in power spectral analysis of HRV following endurance training is not however related with neural regulation of blood pressure (29). Maintaining blood pressure at higher level by resistance trained individuals might be beneficial in tolerating orthostatic stress better after head down bed rest. A wide variety of algorithms and models have been proposed in this regard to study spontaneous heart rate variability, blood pressure variability under different conditions and to characterize the relation between the changes in HR, arterial BP, and respiration. However, the optimal methods for obtaining such information and the most appropriate interpretations of the results obtained are still matters of considerable debate (30-31). In conclusion, the present study demonstrates a significant increase in sympathetic input and non-significant change in parasympathetic input during orthostatic stress in endurance trained individuals. This has caused comparatively higher increase in HR during orthostatic stress, perhaps predisposing them to more orthostatic intolerance after head down bed rest. Relatively, lower HF spectral power and attenuated increase in LF spectral power during orthostatic stress in resistance group, might be beneficial in maintaining orthostatic stress after head down bed rest.

Conflict of Interest

Nil

Acknowledgement

The authors are thankful to the participant who voluntarily participated in the study, without whose active support the study could not have been possible. Thanks are due to Commandant, Dy Comdt, and OIC Sports, Lt Col Dhiraj Sandhir, MEG & Centre for detailing endurance and resistance trained participants. Thanks are also due to Air Cmde Satish Chowdhary and Air Cmde Deepak Gaur for their support and encouragement in the study. The authors are thankful to Gp Capt KK Tripathi, Chief Research Officer, for helping to analyse the data. Last but not least, the authors are thankful to JWO Paritosh Misra and Cpl Subhash, Medical Assistants of the Department who helped in recording various physiological parameters during the study.

Table 1 – Analysis of heart rate variability in Endurance and Resistance trained individuals at baseline, during first 5 min and 6-10th min of tilt test before and after head down bed rest (Values are in mean ±SD)

		BL	First 5 min HUTT 1	6-10th min HUTT 1	HDBR	First 5 min HUTT 2	6-10th min HUTT 2
Mean RR (ms)	Endurance trained	982.5 ±122.2	751.1 *** ±135.2	752.6 *** ±128.9	986.1 ±120.5	722.7 *** ±138.7	709.2 *** ±125.7
	Resistance trained	939.8 ±154.5	840.46 ±121.4	825.1** ±101.5	927.0 ±105.9	813.3 ±109.8	816.1 ±108.7
SDNN (ms)	Endurance trained	45.3 ±12.5	49.0 ±18.7	50.6 ±14.7	45.3 ±19.2	42.5 ±12.4	34.7 ±18.7
	Resistance trained	57.0 ±18.7	47.9 ±18.7	45.7 ±21.7	56.2 ±19.4	48.0 ±15.4	50.7 ±21.9
Mean HR (bpm)	Endurance trained	61.6 ±12.5	80.7 *** ±15.8	80.7 *** ±10.8	61.3 ±17.8	84.2 *** ±10.5	86.0 *** ±9.8
	Resistance trained	65.3 ±15.6	73.1 ±19.8	74.2** ±25.7	66.8 ±21.8	75.7 ±14.8	74.8** ±24.5
RMSSD (ms)	Endurance trained	53.3 ±10.2	31.5 ±10.5	50.8 ±9.8	49.3 ±8.7	38.0 ±10.5	21.2 ±19.5
	Resistance trained	70.4 ±15.4	44.4 ±18.9	47.1 ±12.5	59.9 ±12.3	48.9 ±9.6	55.3 ±11.6
VLF (ms^2)	Endurance trained	113.5 ±25.5	115.5 ±24.8	128.8 ±20.5	86.5 ±19.7	105.9 ±29.2	68.9 ±15.6
	Resistance trained	133.7 ±14.6	293.9 ±12.5	167.3 ±32.8	426.8 ±54.8	223.3 ±59.7	143.0 ±25.8
LF n.u.	Endurance trained	51.5 ±11.9	75.3 * ±12.5	71.0 ±12.5	42.7 ±10.5	77.4 ** ±18.7	76.8 ** ±15.8
	Resistance trained	50.7 ±12.5	71.1 ±18.7	64.9 ±11.9	62.4 ±15.4	71.6 ±15.8	72.3 ±19.4
HF n.u	Endurance trained	46.2 ±10.7	27.4 ±8.6	29.2 ±9.6	52.3 ±10.5	22.3 ** ±7.8	24.7 * ±6.5
	Resistance trained	49.2 ±12.5	28.7 ±8.4	34.9 ±10.5	37.2 ±10.5	28.0 ±8.1	27.3 ±10.7
LF: HF	Endurance trained	1.67 ±0.95	4.16 ±2.13	3.59 ±2.49	1.45 ±1.12	5.81*** ±2.4	4.89 * ±2.72
	Resistance trained	1.13 ±0.89	3.61 ±2.54	2.70 ±1.29	2.07 ±0.87	4.15 ±1.19	3.59 ±2.89

Two way repeated measure ANOVA. Two factors were type of training (i.e. E and R training) and conditions of testing like BL, HUTT1, HUTT2, HDBR, HUTT3 and HUTT4

*/ **/*** significantly different from baseline at $p<0.05$, $p<0.01$ and $p<0.001$ respectively

BL: baseline supine; HUTT: Head up tilt test; HDBR: head down bed rest;

HUTT 1-4 represents 1: First 5 min of HUTT before HDBR; 2: 6th-10th min of HUTT before HDBR; 3: First 5 min of HUTT after HDBR; 4: 6th- 10th min of HUTT after HDBR

Mean RR: Mean R-R interval

SDNN: Standard deviation of R-R intervals

RMSSD: Root mean square of successive differences between adjacent R-R

VLF: Very low frequency (0.00-0.04 Hz)

LF n.u.: Low frequency component of HRV (0.04-0.15 Hz) expressed in normalized unit

HF n.u.: High frequency component of HRV (0.15-0.40 Hz) expressed in normalized unit

LF/HF: Ratio of low frequency to high frequency

Disclaimer

The opinions expressed in this article are those of the author and do not reflect the official views of the Indian Air Force. Or the Indian Society of Aerospace Medicine

Table 2 – Blood pressure data of Endurance and Resistance trained individuals at baseline, during tilt test before and after head down bed rest

Blood Pressure		BL	HUTT 1	HDBR	HUTT 2	Level of significance
Mean RR (ms)	Endurance trained	106.7±6.06	107.0±6.42	105.2±3.49	119.0±14.20 ^	F(3,48)=3.38 P=0.03
	Resistance trained	117.5±9.03*	136.3±20.11 **	134.2±15.12 ***	152.8±8.75 ***###	F(3,44)=6.64 P=0.003
SDNN (ms)	Endurance trained	67.7±7.98	73.5±12.02	69.8±8.94	84.7±8.82	F(3,48)=1.17 P=0.345
	Resistance trained	77.3±12.25	98.7±11.26	81.3±8.96	116.3±10.25 ** ###	F(3,44)=4.75 P=0.011
Mean HR (bpm)	Endurance trained	75.7±7.45	81.7±6.59	78.7±4.23	97.0±11.24 ##	F(3,48)=5.27 P=0.007
	Resistance trained	85.5±8.56	106.5±9.23 **	100.0±10.96 **	124.5±6.77 ** ###	F(3,44)=8.83 P=0.000

^/ # Intragroup comparison

^ significantly different from HDBR at p<0.05

Significantly different from BL,## p<0.01; ### p<0.001

* Intergroup comparison between endurance and resistance trained individuals, * p<0.05; ** p<0.01; *** p<0.001

BL-baseline; HUTT1- head up tilt test before HDBR; HDBR- head down bed rest; HUTT2- head up tilt test after HDBR

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