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A. GĄSIOROWSKA[1], T. MIKULSKI[1], J. SMORAWIŃSKI[2], H. KACIUBA-UŚCIŁKO[1], G. CYBULSKI [1], A. W. ZIEMBA[1], K. KRZEMIŃSKI[1], W. NIEWIADOMSKI[1], K. NAZAR[1]

CARDIOVASCULAR AND NEUROHORMONAL RESPONSES TO LOWER BODY NEGATIVE PRESSURE (LBNP): EFFECT OF TRAINING AND 3 DAY BED REST

[1]Department of Applied Physiology, Medical Research Centre, Polish Academy of Sciences, Warsaw, Poland, [2]Department of Sport Medicine, Academy of Physical Education, Poznan, Poland

Both intensive training and bed confinement impair orthostatic tolerance, however, moderate training may exert beneficial effect on cardiovascular adjustment to gravitational stimuli. It was hypothesized that moderate training attenuates effects of bed rest. To test this assumption 24 healthy male volunteers aged 20.8±0.9 yrs were subjected to 6° head down bed rest (HDBR) for 3 days before and after 6 weeks of moderate endurance training. Before and after HDBR graded LBNP tests (-15, -30, -50 mmHg) were performed. During these tests heart rate (HR), stroke volume (SV), blood pressure (BP), plasma catecholamines, ACTH, adrenomedullin, atrial natriuretic peptide, plasma renin activity (PRA) and hematocrit were determined. HDBR did not systematically influence LBNP tolerance up to -50 mmHg, but it enhanced rates of reduction of SV, cardiac output and systolic BP and increased elevations of HR and PRA. Training did not alter significantly effects of HDBR on LBNP-induced changes in HR, SV, CO and TPR but it attenuated decrease in systolic BP and diminished increases in plasma noradrenaline and PRA. In conclusion, training has negligible effect on the HDBR-induced changes in central hemodynamics during LBNP but may increase vascular sensitivity to some vasoconstricting factors.

Key words: *orthostatic tolerance, head down bed rest, endurance training, haemodynamics, hormones*

INTRODUCTION

Lover body negative pressure (LBNP) is a laboratory test simulating orthostasis. It decreases central venous pressure and stroke volume and eventually leads to syncope due to the decreased brain perfusion. Unloading of arterial and cardiopulmonary receptors by the blood pressure and volume changes induces counterregulatory responses increasing heart rate (HR) and peripheral vascular resistance. These responses include decreased activity of parasympathetic innervation of the heart, activation of the sympathetic outflow to the heart and peripheral vessels (1, 2), increased secretion of catecholamines (3 - 5), increased plasma renin activity (3, 5) and diminished release of atrial natriuretic hormone (6, 7). Increased secretion of vasopressin (4, 8), galanine (8), and ACTH (5) occurs when blood pressure drops markedly or the presyncopal symptoms appears. In addition, orthostatic stress causes an increase in plasma adrenomedullin (5, 9), which may play a role in the cardiovascular adjustment to central hypovolemia by stimulation of cardiac contractility.

There is a body of evidence that bed rest in horizontal and especially in head down position (see 10) as well as intensive endurance training (see 11, 12) lead to the impairment of orthostatic tolerance.

Inadequate circulatory responses to gravitational stimuli after bed rest of various duration are due to a combination of many factors including reduction of plasma volume (13, 14) decreased sensitivity of carotid baroreflex (15), increased venous compliance (16, 17), attenuated arterial vasoconstriction (18 - 20) and cardiac atrophy (21, 22). Moreover, indirect evidence indicate also the alterations in autonomic function which manifest themselves as a decrease in total heart rate variability and high frequency power spectrum suggesting diminished activity of the parasympathetic nervous system (23, 24).

Intensive endurance training may diminish orthostatic tolerance as a result of remodeling of the heart increasing ventricular compliance and steeper volume-pressure curve leading to excessive decrease in stroke volume during orthostasis (25). The other mechanisms which are considered to be responsible for a high incidence of orthostatic intolerance among endurance athletes include attenuated carotid baroreceptors responsiveness (26, 27) and diminished reactivity of blood vessels to the sympathetic stimulation (28).

On the other hand several studies demonstrated that moderate training may improve orthostatic tolerance (29 - 32). According to the Convertino (29) training exerts the beneficial effect on tolerance of gravitational stimuli when it does not increase maximal oxygen uptake above 55-60 $ml \cdot kg^{-1} \cdot min^{-1}$. It is hypothesized, therefore, that moderate training may also attenuate the debilitating effects of bed rest on cardiovascular responses to orthostatic challenges. The present study was designed to check this assumption. Thus, haemodynamic and neuro-endocrine responses to LBNP were studied in healthy men who were subjected to the three-

day 6° head down bed rest (HDBR) twice: before and after six weeks of moderate endurance training.

MATERIAL AND METHODS

Subjects

Twenty four healthy male students of the Military Academy (age: 20.8±(SD)0.9 yrs, body mass: 74.2±(SD)7.1 kg, height: 176.9±(SD)4.3 cm, maximal oxygen uptake: 47±(SD)4 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered to take part in the study after giving informed consent. All lived in the Students' Hostel, had similar daily activities and the same controlled diet. They were nonsmokers, in good health, nonobese and normotensive. None of them reported tendency toward syncope when standing or taking any medications. They were physically active but not involved in the regular sport training. The study protocol was approved by Ethical Committee of the Medical University School in Poznan, Poland.

Study protocol

Before and after six weeks of endurance training the subjects were confined to bed for three days with the 6° head down position (HDBR). Before and after both HDBR periods (HDBR1 and HDBR2) they were submitted to the graded LBNP test.

The training program included 5 sessions per week lasting 60-90 min. The training sessions consisted of 10 min jogging at heart rate (HR) of 120-130 beats/min, 30 min of constant rate running at 60-70% of $\dot{V}_{O_2\,max}$, interval running with the maximal speed for 150-200 m, and 30 min of swimming or soccer.

To evaluate the effectiveness of training, three days before both HDBR periods the subjects performed an incremental exercise test until volitional exhaustion during which $\dot{V}_{O_2\,max}$ was determined. Exercise load was increasing by 50 W every three min starting from 50W. Oxygen uptake was measured using the Vmax 29 system (SensorMedics, USA).

During HDBR the subjects were under medically supervised conditions in specially configured rooms in the Students' Hostel. They drank 1L of carbonate free mineral water per day, and their total energy intake was 12,000 kJ/day (50% carbohydrates, 35% fat and 15% protein).

In the evening before both HDBR periods the subjects reported to the laboratory where they spent the night. In the morning, after an overnight fast they were carried on the stretcher in the supine position to the LBNP chamber, which was sealed at the level of iliac crest. Thirty min after inserting catheter to the antecubital vein and instrumentation two baseline circulatory measurements were made and blood sample for hormone and hematocrit (HTC) determinations was taken at ambient pressure. Then the subjects were submitted to serial LBNP: 10 min at -15 mmHg, 10 min at -30 mmHg and 10 min at -50 mmHg or until onset presyncopal sighs or symptoms, and after 10 min of the recovery period at ambient pressure. The presyncope symptoms and signs included lightheadness, nausea, sweating, narrowing of vision and rapid drop of systolic blood pressure by more that 20 mmHg or bradycardia. Before and every 3 min during LBNP and the recovery period blood pressure (BP), heart rate (HR), stroke volume (SV), cardiac output (CO) were measured. Blood samples for epinephrine (E), norepineohrine (NE), adrenomedullin (ADM), atrial natriuretic peptide (ANP) and ACTH concentrations and plasma renin activity (PRA) and HTC were taken at the end of final LBNP stage. Identical LBNP tests were repeated after completion of both HDBR periods.

Methods

For LBNP the chamber with the pressure control system was used (ITAM, Zabrze, Poland). It allows to change pressure within approx. 15 s. Heart rate was monitored and recorded by the Sport Tester (PE 3000, Polar Electro, Finland). Blood pressure (BP) was measured on brachial artery by electronic sphygmomanometer. Stroke volume (SV) and cardiac output (CO) were determined by impedance cardiography (ICG) using a monitoring device designed in the Medical Research Centre, Polish Academy of Sciences by Cybulski *et al.* (33). The measurement is based on the tetrapolar technique: the sinusoidal alternating current (95 kHz) is applied *via* the pair of electrodes placed on the chest, the voltage signal is collected from other electrodes and demodulated. The ECG and the first derivate of the impedance signal are sampled at the rate of 200 Hz. The system allows for the off-line, beat-to-beat automatic evaluation of stroke volume (SV), and HR and cardiac output (CO). Validity of SV measurements was determined using echocardiography ($r=0.90$, $n=21$, $p<0.001$) (34). Mean blood pressure was calculated as diastolic BP plus 0.33 of difference between systolic and diastolic BP then the total peripheral resistance (TPR) was calculated dividing mean BP by CO and expressed in arbitrary peripheral resistance units (PRU). Changes in plasma volume during LBNP were calculated from differences in blood hematocrit. Mean hematocrit values were obtained by multiplying venous blood hematocrit by 0.8723.

Blood samples for catecholamine determination were taken to the chilled polyethylene tubes containing EGTA and reduced glutathione while for other hormones the tubes with EDTA with aprotinin (Trasylol, 500 KIU/ml blood) were used. All samples were centrifuged within 30 min at 3000 rpm at 4°C, and stored at -70°C until further processed.

Plasma [E] and [NE] were measured using high pressure liquid chromatography. Other hormones were determined by radioimmunoassay using CIS bio international (France) kits for plasma [ACTH] and [ANP], Phoenix Laboratories. (Belmont, CA, USA) reagent set for [ADM] and Immunotech, Angiotensin I kit (Prague, Czech Republic) for PRA.

Data analysis and statistics

To evaluate the effect of HDBR1 and HDBR2 on cardiovascular indices during LBNP up to -30 mmHg, that is the level tolerated by all subjects, two way analysis of variance for repeated measures and *post hoc* a paired Student's t test were used. Besides, the incremental areas under the curves of these indices up to -30 mmHg during each LBNP test were calculated, and then compared using a paired Student's t test. Normality of distribution was checked using a Shapiro-Wilk test W. The differences in neuro-endocrine variables were evaluated also by a paired Student's t test. As the level of significance $p<0.05$ was accepted. The data are presented as means with standard errors (SEM) unless otherwise stated.

RESULTS

Cardiovascular and neurohormonal responses to LBNP

Analysis of the combined four LBNP tests showed significant reduction of plasma volume ($p<0.0001$), increases in HR and TPR ($p<0.0001$), and decreases in systolic BP ($p<0.0001$), SV ($p<0.0001$) and CO ($p<0.0001$). Plasma concentrations of norepinephrine ($p<0.001$), epinephrine ($p<0.001$), ACTH ($p<001$) and adrenomedullin ($p<0.01$) as well as plasma renin activity (PRA)

($p<0.001$) increased while plasma level of atrial natriuretic peptide (ANP) declined ($p<0.01$) significantly.

Effects of training on the subjects' aerobic capacity and LBNP tolerance

Training causes an increase in $\dot{V}_{O_2\,max}$ from to 47 ± 1 to 52 ± 2 $ml \cdot kg^{-1} \cdot min^{-1}$ ($p<0.001$). In the initial LBNP test 13 subjects completed the test while in 11ones LBNP was stopped at - 30 mmHg (6 subjects) or at the first 3 min at -50 mmHg (5 subjects) because of the presyncopal signs or symptoms. After training, in 6 subjects the LBNP tolerance was improved while in one it was diminished. As a result, after training 18 subjects withstood the whole paradigm. The accompanying cardiovascular and neuro-hormonal changes were described in details elsewhere (5, 32). Briefly, the subjects with low LBNP tolerance showed greater rates of SV, CO and BP decline, higher HR and lower TPR as well as greater increases in plasma catecholamines, ACTH and PRA than those who completed the test. The post-training improvement in LBNP tolerance was associated with attenuated rate of HR increase and lowered rates of SV, CO and BP decline during LBNP without significant alterations in neuro-hormonal changes except inhibition of the rise of plasma ACTH concentration, which occurred at the end of the test. In the whole group of subjects there were no significant differences in the cardiovascular and neuro-hormonal indices measured before and after training under basal condition and during LBNP except plasma ACTH concentration at the end of the test, which was lower after than before training ($p<0.05$).

Effect of HDBR on LBNP tolerance and cardiovascular responses to LBNP tests

Confinement to bed for 3 days did not influence LBNP tolerance up to -50 mmHg in a systematic manner. After the first HDBR (HDBR1) 14 subjects completed the test without presyncopal signs or symptoms while in the remaining ones it was stopped at -30 mmHg. Comparing with the initial test there was an impairment in LBNP tolerance in 4 subjects, an improvement in 5 subjects and no alteration in 15 subjects. After the second HDBR (HDBR2) the number of subjects who completed the test was also 14. An impairment of LBNP tolerance was noted in 6 persons and an improvement in 3 subjects.

The mean values of cardiovascular indices during LBNP tests in the whole group of 24 subjects are presented in *Figs. 1* and *2* while the integrated responses of cardiovascular variables to LBNP up to -30 mmHg expressed as areas under the curve are shoved in *Table 1*. All the LBNP tests caused significant increases in HR ($p<0.001$) and TPR ($p<0.01$ before HDBR1 and $p<0.001$ during the remaining tests), and significant decreases in systolic BP ($p<0.01$ before HDBR1 and $p<0.001$ during the remaining tests), SV ($p<0.001$) and CO ($p<0.01$ before HDBR1 and $p<0.001$ during the remaining tests).

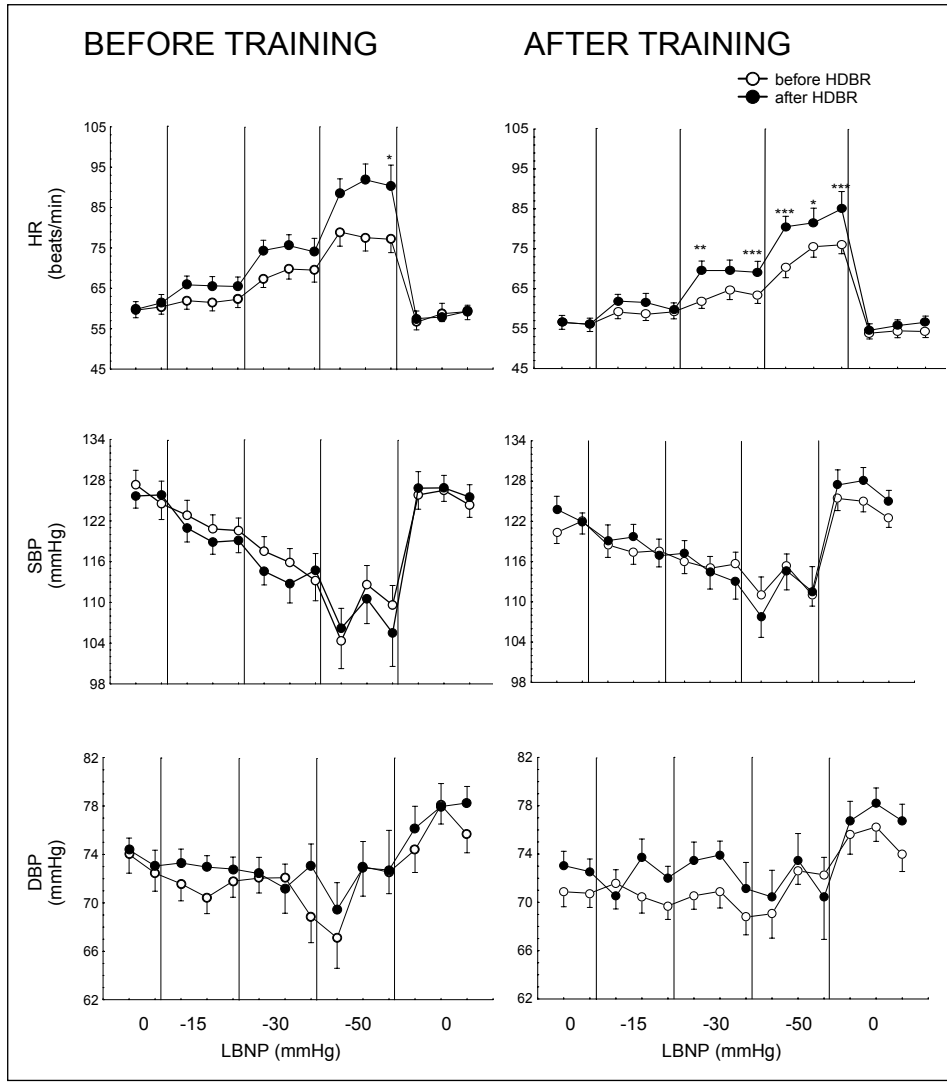

Fig. 1. Effects of LBNP on heart rate (HR), systolic blood pressure (SBP) and diastolic blood pressure (DBP) before HDBR (open circles) and after HDBR (close circles). The values are means ± SE; asterisks denote significance of differences between the tests performed before and after HDBR: * $p<0.05$, ** $p<0.01$; *** $p<0.001$

Both before and after training the effects of HDBR on HR values during LBNP up to -30 mmHg was insignificant (ANOVA $p>0.05$) but there was tendency towards toward greater rate of HR increases after than before both HDBR periods as indicated by interaction of LBNP and HDBR1 (ANOVA $p=0.070$ after HDBR1 and $p<0.05$ after HDBR2). Also the incremental areas

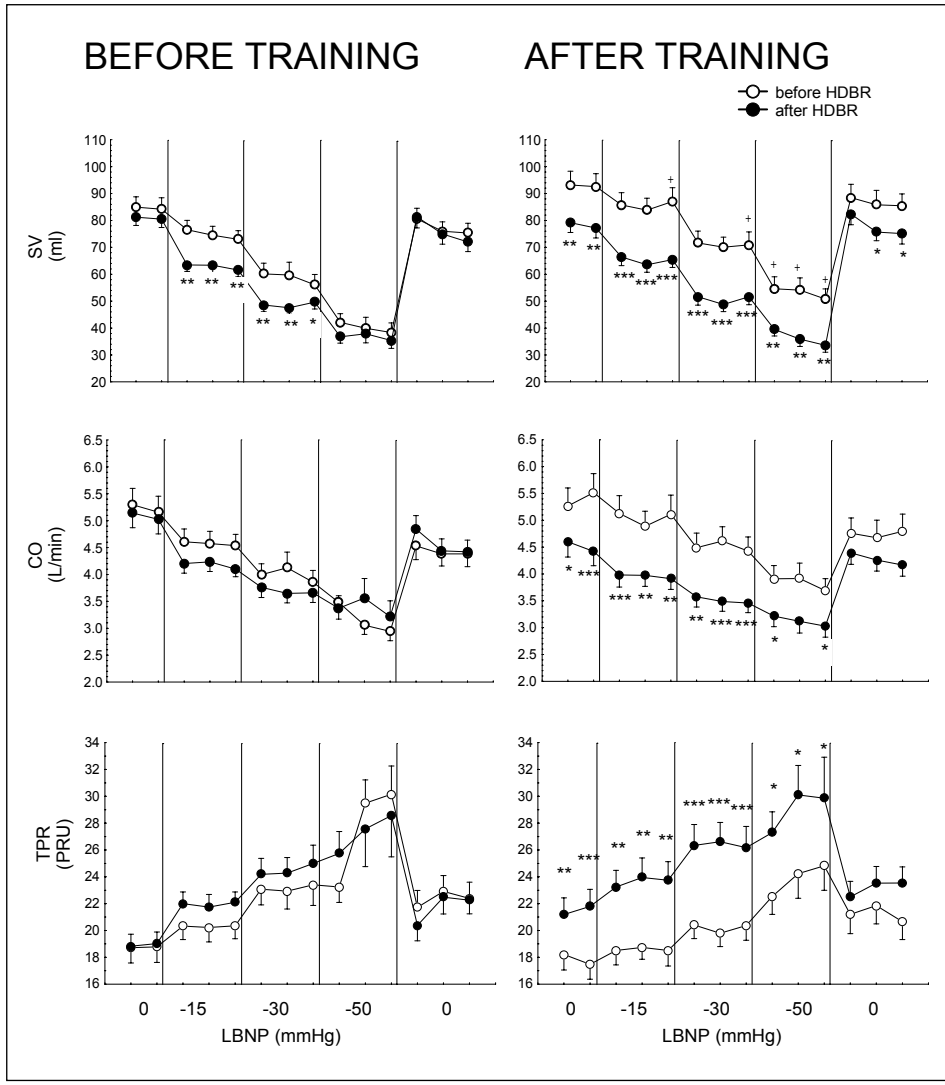

Fig. 2. Effects of LBNP on stroke volume (SV), cardiac output (CO) and total peripheral resistance (TPR) before HDBR (open circles) and after HDBR (close circles). The values are means ± SE; asterisks denote significance of differences between the tests performed before and after HDBR: * $p<0.05$, ** $p<0.01$; *** $p<0.001$; crosses denote significance of differences between the values obtained before and after training : † $p<0.05$.

under the HR curve during LBNP up to -30 mmHg were greater after than before HDBR ($p<0.05$). The effects of HDBR1 and HDBR2 on HR response to LBNP were similar. Analysis of variance did not revealed significant differences in systolic and diastolic BP between LBNP tests performed before and after HDBR

Table 1. Integrated cardiovascular responses to LBNP up to -30 mmHg presented as incremental areas under the curve.

Variable	HDBR1			HDBR2		
	Before	After	Diff.	Before	After	Diff
HR (beats)	75 ± 18 (24)	141 ± 22 (23)	65 ± 25* (23)	74 ± 22 (23)	137 ± 20 (24)	63 ± 24* (23)
SV (ml · min)	-273 ± 54 (24)	-404 ± 42 (22)	-137 ± 46** (22)	-210 ± 46 (23)	-309 ± 43† (24)	-82 ± 46 (23)
CO (L)	-14 ± 3 (24)	-18 ± 3 (22)	-6 ± 3* (22)	-11 ± 12 (23)	-11 ± 3† (24)	0 ± 3 (23)
SBP (mmHg · min)	-92 ± 19 (24)	-138 ± 24 (23)	-48 ± 22* (23)	-83 ± 18 (23)	80 ± 16†† (24)	7 ± 28† (23)
DBP (mmHg · min)	-18 ± 16 (24)	-5 ± 18 (23)	-17 ± 53 (23)	-1 ± 12 (23)	1 ± 15 (24)	2 ± 18 (23)
TPR (PRU · min)	46 ± 15 (24)	69 ± 9 (22)	26 ± 12* (22)	28 ± 9 (23)	51 ± 12 (24)	23 ± 12 (23)

The values are means ± SE and the number of subjects is given in parentheses;
HR – heart rate, SV - stroke volume, CO – cardiac output, SBP – systolic blood pressure, DBP – diastolic blood pressure, TPR – total peripheral resistance; asterisks denote significance of differences between the tests performed before and after HDBR: * $p<0.05$, ** $p<0.01$; crosses denote significance of differences between the values obtained before and after training : † $p<0.05$, †† $p<0.01$.

either before or after training. However, comparison of integrated responses represented by areas under the curve by the Student t test for paired data showed that before training systolic BP decrease during LBNP up to -30 mmHg was greater after than before HDBR ($p<0.05$) and greater after HDBR1 than after HDBR2 ($p<0.01$).

After both HDBR periods SV values were significantly diminished ($p<0.05$ after HDBR1 and $p<0.001$after HDBR2). There was also tendency towards greater rate of SV decline after than before HDBR1 (ANOVA interaction $p=0.071$). During LBNP applied before HDBR2, SV values were significantly higher than before HDBR1 ($p<0.05$) but the there was no difference between SV values measured after HDBR 1 and after HDBR2. Comparisons of areas under the SV curve shoved significant difference between values obtained after and before HDBR1 ($p<0.01$) and between the tests performed after HDBR1 and after HDBR2 ($p<0.05$). Effect of HDBR on CO values evaluated by ANOVA appeared to be significant only after training ($p<0.01$) but the rate of decline tended to be smaller during LBNP applied after HDBR2 than after HDBR1 ($p=0.058$). The integrated CO response to LBNP was greater after than before HDBR1 and smaller during the test performed after HDBR2 than after HDBR1.

Analysis of variance revealed that before training TPR values and time-course of its increase during LBNP were not significantly altered by HDBR while after training the values of TPR and the rate of their elevation during LBNP were

greater after than before HDBR ($p<0.01$and $p<0.05$, respectively). However, comparison of integrated responses to LBNP showed before and after HDBR showed significant ($p<0.05$) increase before training and strong tendency ($p=0.070$) toward increase after training.

The calculated from blood hematocrit decreases in plasma volume caused by HDBR1 and HDBR2 did not differ significantly (7.9 ± 2.8 vs 6.7 ± 1.9%, respectively). HDBR did not alter plasma volume changes during the LBNP tests. All the LBNP tests caused significant ($p<0.001$) decreases in plasma volume (7.5 ± 1.9% before HDBR1, 8.5 ± 2.0% after HDBR1, 8.3 ± 1.7% before HDBR2 and 10.2 ± 1.3%, after HDBR2).

Effect of HDBR on neuro-hormonal responses to LBNP tests

The mean values of plasma hormone concentrations and renin activity are presented in *Figs 3* and *4*. All the LBNP tests caused the significant increases in plasma NE ($p<0.001$), E ($p<0.001$), ADM ($p<0.01$) and ACTH ($p<0.05$ after training before HDBR and $p<0.001$ in the remaining tests) concentrations as well as in PRA ($p<0.001$). Plasma ANP significantly decreased during LBNP in all tests ($p<0.01$).

Before training, HDBR increased significantly the values of plasma renin activity ($p<0.001$) and an increase in this enzyme activity induced by LBNP ($p<0.001$). The other neuroendocrine indices were not significantly affected by HDBR1. After training, during LBNP applied before HDBR2 the plasma ACTH concentrations were lower than during the initial test ($p<0.05$) and the increases induced by LBNP in plasma ACTH and ADM concentrations were attenuated ($p<0.05$). Plasma NE response to LBNP was smaller after than before HDBR2 ($p<0.01$) while the PRA ($p<0.01$) and ACTH ($p<0.01$) responses were increased. The changes in the remaining hormone concentrations were not affected by HDBR2. Comparison of neuro-endocrine responses to LBNP applied after HDBR2 and HDBR1 showed significantly smaller increases in plasma NE ($p<0.05$), PRA ($p<0.05$) and ADM ($p<0.05$).

DISCUSSION

Training applied in the present work was relatively short and not very intensive but it increased the subjects' aerobic capacity by approx. 10%. Since the subjects were submitted to LBNP until presyncope or -50 mmHg level, we are unable to quantify their orthostatic tolerance. However, the data showed that after training the number of subjects showing presyncope was reduced. This study confirmed, therefore, that moderate endurance training can increase orthostatic tolerance. The new finding is that it modified the effect of HDBR on the cardiovascular and neurohormonal response to LBNP, namely it attenuated a

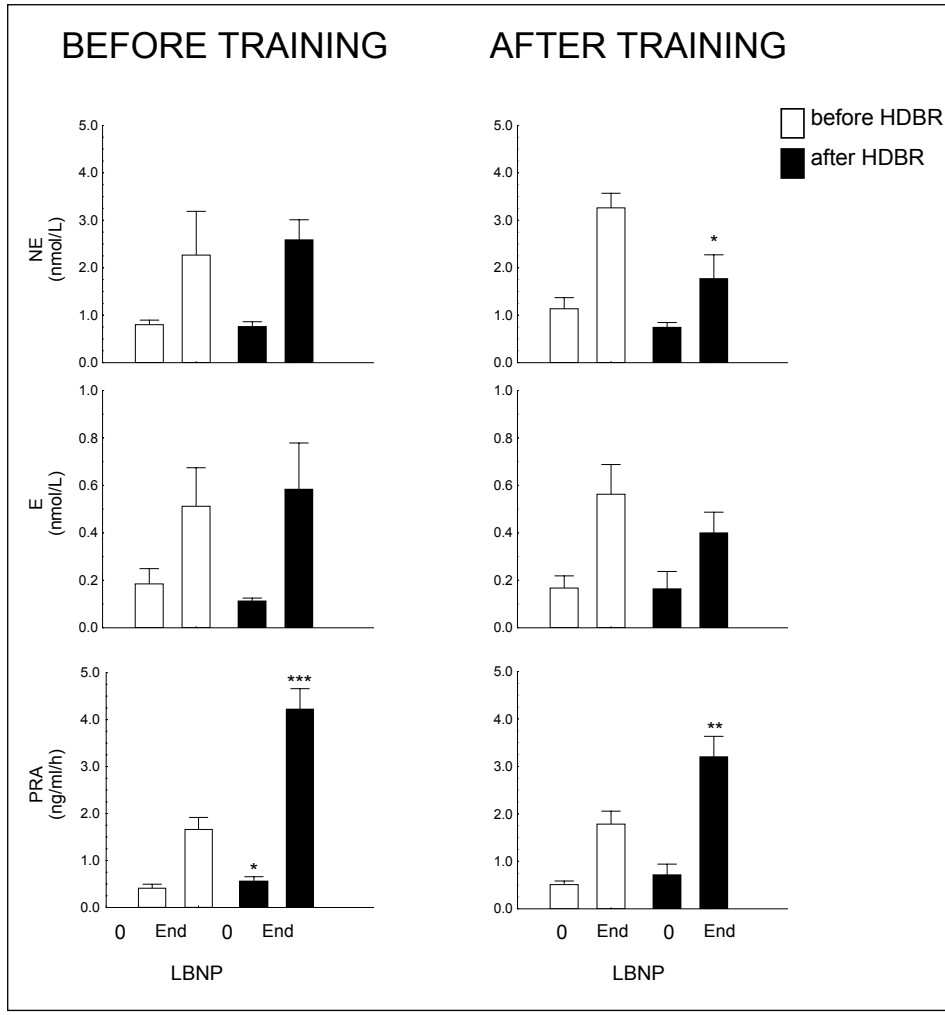

Fig. 3. Effects of LBNP on plasma concentrations of epinephrine (E) and norepineprine (NE) and plasma renin activity (PRA) before HDBR (open bars) and after HDBR (close bars). The values are means ± SE; asterisks denote significance of differences between the tests performed before and after HDBR: * $p<0.05$, ** $p<0.01$; *** $p<0.001$.

decrease in systolic blood pressure with the strong tendency towards greater increase in TPR and reduced the increases in PRA and norepinephrine.

Neither before nor after training three-day-HDBR systematically affected tolerance of LBNP up to -50 mmHg but it affected cardiovascular responses to this stimulus. In accordance with the previously reported investigations concerning effects of bed rest of duration from 6 hours to several weeks (see 10) our study demonstrated the reduction of plasma volume and amplified increases

of HR and decreases of SV during LBNP after both HDBR periods. The LBNP-induced decrease in SBP became more pronounced after than before HDBR only before training.

The most pronounced change in neurohormonal response to LBNP induced by HDBR is an exaggerated increase in plasma renin activity. Before training HDBR caused also an elevation of PRA under basal condition. This is consistent with the previous data showing elevated PRA and its exaggerated response to gravitational

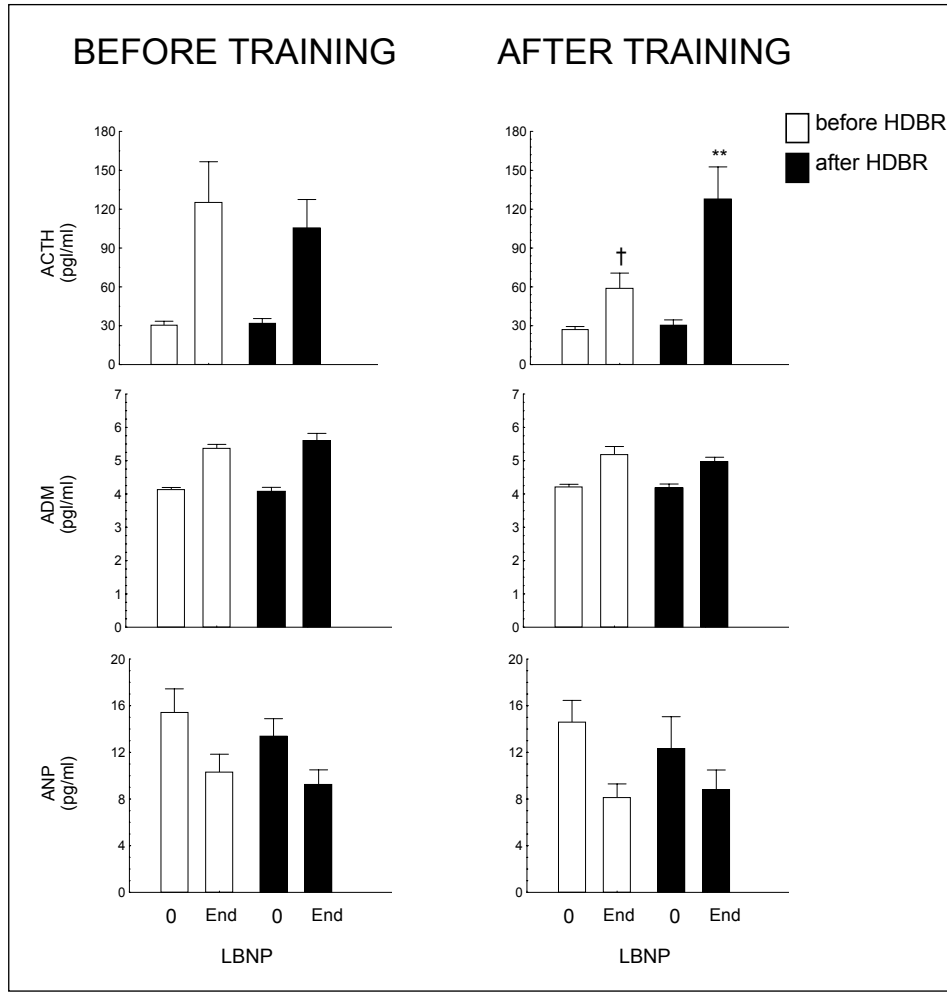

Fig. 4. Effects of LBNP on plasma concentrations of adrenocorticotropin (ACTH), adrenomedullin (ADM) and atrial natriuretic peptide (ANP) before HDBR. (open bars) and after HDBR (close bars) The values are means ± SE; asterisks denote significance of differences between the tests performed before and after HDBR: ** $p<0.01$; crosses denote significance of differences between the values obtained before and after training: † $p<0.05$.

stimulus after bed rest (35). Before training the baseline values of plasma catecholamine, ACTH, ANP and ADM concentrations and their LBNP-induced changes were not modified by HDBR. However, after training the PRA and plasma NE increase during LBNP was attenuated by HDBR while the increase in plasma ACTH was greater after than before HDBR. Comparison of post-HDBR neurohormonal responses to LBNP before and after training revealed that the increases in PRA, the plasma NE and ADM concentrations and a decrease in plasma ANP were smaller after training.

The literature data on the effects of bed rest on the sympathetic responses to gravitational stimuli are not uniform. Khan *et al*. (36) described attenuated muscle sympathetic nerve (MSNA) responses to LBNP after 24 hours of HDBR and Kaciuba-Uscilko *et al*. (37) reported diminished plasma NE response to standing after 3 days of HDBR while Shoemeker *et al*. (38) found blunted MSNA increase during tilt test after 14 days of HDBR. These authors suggested that the changes are caused by the reduction of carotid baroreceptors sensitivity, which has been documented in other studies (15). However, Koska *et al.* (35) reported greater increases in the plasma NE concentration during standing test after four days of HDBR while Millet *et al*. (39) and Pawelczyk *et al.* (40) did not found any alterations in plasma catecholamine or MSNA responses to orthostatic stimuli after HDBR lasting 7 and 18 days, respectively.

There are only few data concerning an effect of training on the adrenergic response to gravitational stimuli. The data obtained by Gabbett *et al.* (41) in the elderly healthy men and by Hagberg *et al.* (42) in hypertensive adolescents did not show any changes in plasma NE response to the orthostatic stress. However, Koska *et al.* (35) demonstrated attenuated plasma NE increases during standing in healthy adult men and Winker *et al*. (31) in patients with orthostatic hypotension after training. This in line with the data showing diminished baroreceptor sensitivity after training (30). The present data showed the attenuated increase in plasma NE during LBNP after HDBR preceded by training that may indicate diminished activation of the sympathetic nervous system only under this condition. This may indicate additive effect of training and HDBR.

The reduction in PRA response to LBNP found after HDBR2 may be secondary to the diminished sympathetic activation although the opposite can be also considered, since the relationship between the renin-angiotensin-aldosterone system and sympathetic system is biderectional (43). The limitation of this study is that we did not determine plasma volume. Basing on changes in hematocrit it can be suggested that training did not affect decreases in plasma volume induced by HDBR and LBNP. However, we had not data on the influence of training on plasma volume. In the literature there is a body of evidence indicating an increase in plasma volume after endurance training (see 44). If this effect occurred in our subjects it could affect the responses to HDBR and subsequent LBNP test resulting in diminished increases in PRA and ANP (see 45).

The smaller increases plasma adrenomedullin concentration during LBNP test following HDBR after training than those occurring under the same condition before training may depend on reduced plasma NE or PRA elevations. Rossler *et al*. (9) reported high correlation between plasma NE and ADM increases during orthostatic stress which suggest that sympathetic nervous system is involved in stimulation of ADM release while the study of Ishimitsu *et al*. (46) provided evidence of the molecular link between NE and adrenomedullin gene expression. It is documented also that angiotensin II stimulate this peptide secretion (47).

It is of interest that in spite of lower rise of plasma NE concentration and PRA during the last LBNP test the increase in total peripheral resistance was not reduced. This may suggest that after training the sensitivity of blood vessels to vasoconstricting factors was elevated.

In summarizing, the present study demonstrated that moderate endurance training did not modify significantly the effect of three day HDBR on heart rate, stroke volume, cardiac output and plasma volume responses to submaximal LBNP but it attenuated a decrease in systolic blood pressure, and increases in norepinephrine and plasma renin activity without compromising the rise in total peripheral resistance. These effects of training can be considered as beneficial from the point of view of maintenance of orthostatic tolerance after bed confinement and under condition of weightlessness during space flight.

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Author's address: Prof. dr hab. Krystyna Nazar, Department of Applied Physiology, Medical Research Centre, Polish Academy of Sciences, 5 Pawińskiego Str., 02-106 Warsaw, Poland. Tel/fax (22) 6684554; e-mail: nazar@cmdik.pan.pl