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CHANGES OF SELECTED BIOCHEMICAL, PHYSIOLOGICAL AND DENSITOMETRIC PARAMETERS UNDER LOW FREQUENCY VIBRATION

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The effects of low frequency vibration exposure on the humans were investigated in the Institute of Human Biophysiology of the Academy of Physical Education in Kraków. The research program involved nineteen 1200 s vibrations exposure sessions in the subsequent working days, at the same time of day for each participant. During each session, selected physiological parameters were registered before and after the exposure, the heart beat rate HR and saturation levels SpO_2 were monitored on the constant basis. The research program was supported by the biochemical and densitometric analysis before and after the experiments.

Key words: exposure under vibration, biochemical, physiological and densitometric parameters.

1. Introduction

The chief purpose of the research programme was to investigate, how low-frequency vibrations should affect the selected biochemical parameters (H^+ – hydrogen ion concentration, pCO_2-CO_2 pressure in blood, HCO_3 – bicarbonate buffer component, pO_2 – oxygen pressure in blood, tCO_2 – level of blood saturation with CO_2, $O_{2\mathrm{sat}}$ – level of blood saturation with oxygen, NZ – total sum of buffer anion concentrations in blood, Hb – haemoglobin concentration), physiological ones (PS – systolic pressure, PR – diastolic pressure, T – body temperature, PD – response time (Dietrich test)) and densitometric indices (BMC, BMD).

Cyclic variations of bone loading were induced by harmonic vibrations (transmitted by the human body via legs, pelvis and back sections) of the frequency corresponding to running, most appropriate from the standpoint of physiology.

It is required that these vibrations should be safe and not perceived as nuisance. It was expected that variations in the values of selected parameters would be more sig-

nificant under the low-frequency vibrations exposure than during their absence [2, 4, 6, 8, 10]. These views seemed to be justified by the assumption that these vibrations would be treated as a physical exercise for the human body. Exposure under vibrations would clearly induce shock absorption by the muscles and bone systems, leading to isometric functioning of muscles in the conditions of variable forces acting upon the bones [1, 3, 7, 11].

2. Methodology

The experiments were conducted in the Institute of Human Biophysiology of the Academy of Physical Education in Kraków. The tests were continued for 25 days, from 14.05.2002 to 7.06.2002, covering 19 training sessions. A single training session would last 1800 s (time total), including 1200 s of vibration exposure. Each participant took part in a training session every day (except Saturdays and Sundays), at the same time of day. 13 participants were tested each day. The experiments would begin at 8 a.m. and finish at 4 p.m. Utilised in the tests was a vibrating platform, specially designed and engineered for the purpose of this research programme.

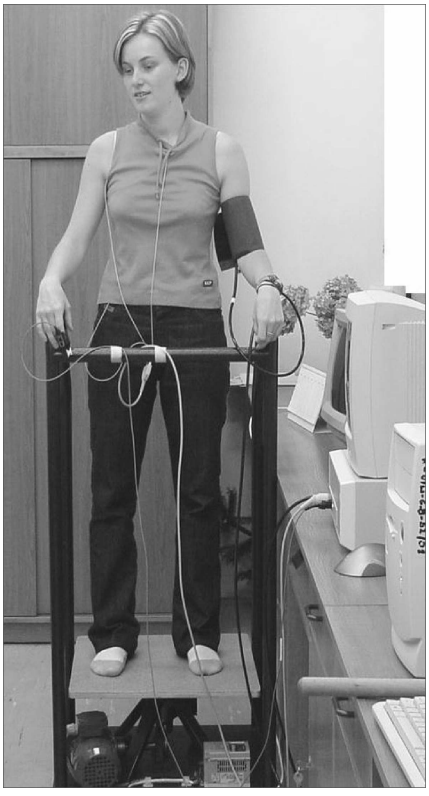


Fig. 1. Test platform.

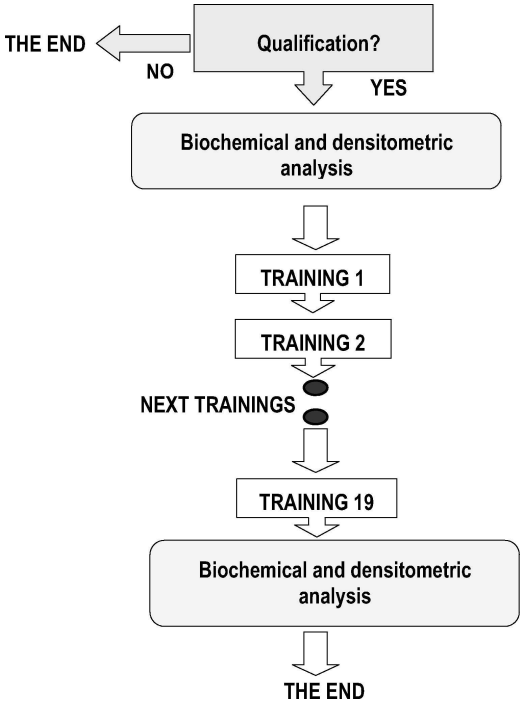


Fig. 2. Time schedule of the experimental programme.

The main component is a steel board with fixed rails made from bent steel pipes, with the attached driving system and the vibrating platform. The driving system comprises a 0.18 kW Besel motor controlled by a L100 Hitachi converter, connected to a driving shaft and a cam mechanism via a clutch mechanism. The cam allows us to switch from the rotating to the progressive motion. Continuos control of frequency in the range 0–3.5 Hz is achieved through the use of a converter (Fig. 1).

The participants were acquainted with the experimental procedure and they all had to give their consent to participate. The algorithm of the qualification procedure before the experiments is shown in Fig. 2. On selecting 13 participants, their blood analyses were taken and relevant densitometric parameters were measured, followed by 19 training sessions using the vibrating platform, each session lasting 20 min. The sessions were continued in the subsequent working days. After 19 sessions, the biochemical and densitometric analyses were repeated and the experimental procedure was finished (Fig. 2).

The pre-test procedure would take about 5 min, covering the Thayer test, gathering information about the participant's medical history and his general feeling, measurements of body temperature, of diastolic and systolic pressure and the fitness test (Dietrich test), see Fig. 3. Afterwards the participant would climb to the platform, the electrodes would be connected and the performance of the monitoring system would be checked (ELMED FX2000), see Fig. 4.

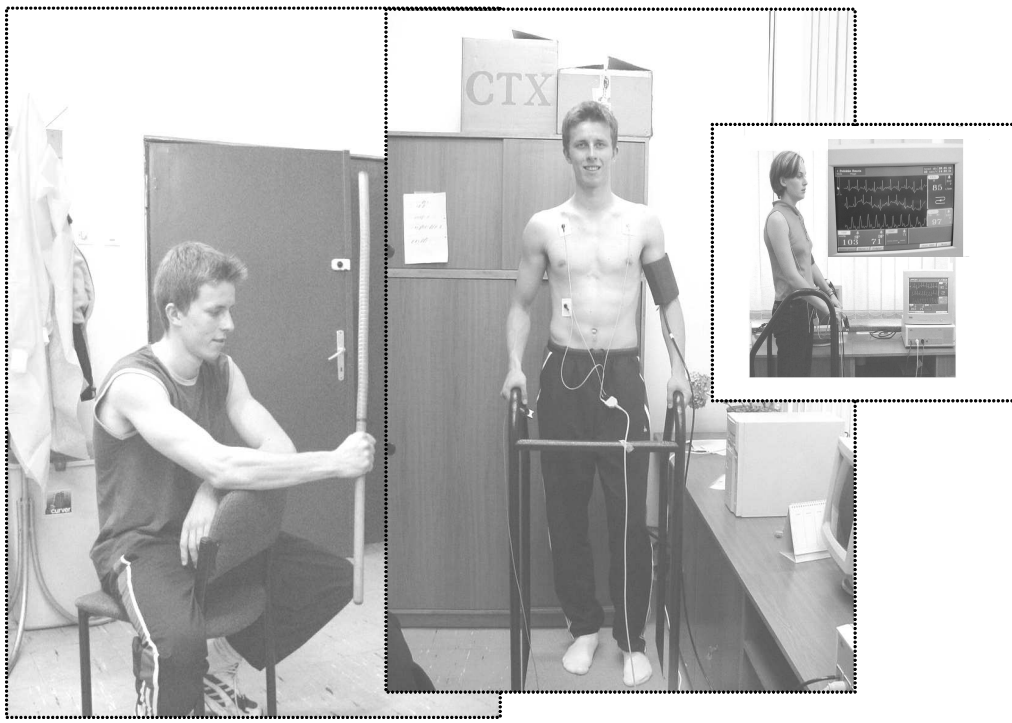


Fig. 3. Dietrich test.

Fig. 4. Monitoring of heart beat rate, pulsoxymetry and pulse rate (system ELMED FX2000).

The pre-test procedure being completed, the main test programme would begin. The participants were subjected to 20 min vibration exposure, supported by on-line and real time acquisition and monitoring of ECG signals, pulse rate/heart beat rate and pulsoxymetry. The participants would stand on the platform with their shoes removed, to eliminate vibration damping by shoe soles. The test programme being executed in accordance with the approved algorithm, the close-up activities were performed. The participants had their systolic and diastolic pressure and body temperature measured again. Afterwards the electrodes were removed, the fitness test (Dietrich test) and the Thayer tests were performed, thus ending the test procedure.

3. Biochemical, physiological and densitometric analyses

Before and after experiments, the blood analyses were taken for biochemical tests:

- Determination of haemoglobin concentration by Drabkin's method, in blood arterialised from venous blood drawn to the test tube as in "clotting" analyses. (In Drabkin's method all of the haemoglobin in a blood sample is converted into cyanomethaemoglobin). The absorbance of cyanomethaemoglobin is measured in a spectrophotometer. Material: capillary blood or well mixed chelate blood (obtained by adding 1 ml of blood to 1–2 mg of dry disodium versenate).

  Apparatus: spectrophotometer for absorbance measurements within the visible spectrum range, cuvettes of the measured layer thickness $d = 1$ cm. Agents used in reactions: 1) – Drabkin's agent: 0.048 g/l KCN, 0.18 g/IK3Fe(CN)$_6$, 0.136g/IKH2PO$_4$, 0.1 g/l detergent, 2) – standard haemoglobin solution with the concentration 16 g/dl (about 10 mmol/l) of haemoglobin.

  Method: Add 0.02 ml of capillary blood or well mixed chelate blood (diluted in the ratio $1 : 25$ l) to 0.5 ml of the Drabkin's agent. Mix well and incubate at room temperature for 5 min. Measure the absorbance (A_b) of the solution at $X = 540$ nm in the cuvette $d = 1$ cm, in comparison to that of Drabkin's agent. Measure the absorbance of the standard solution (A_w) in comparison to water, at the same wavelength.

  Haemoglobin concentration is derived from the formula: Hb (g/dl) = $(A_b/A_w) \times c_w$ or Hb (mmol/l) = $(A_b/A_w) \times c_{w1}$, where A_b – absorbance of the test sample, A_w – absorbance of the standard solution, c_w – concentration of the standard solution in g/dl, c_{w1} – concentration of the standard solution in mmol/l. When high-quality spectrophotometers are used, the measurements of standard absorbance can be omitted and haemoglobin concentration is determined on the basis of blood sample absorbance, using the formulas: Hb (g/dl) = $A_b \times 36.8$ or Hb (mmol/l) $= A_b \times 22.8$. The normal reference range: men: 16.0–18.0 g/dl; women: 12.0–16.0 g/dl, Hb (mmol/l) = $0.62 \times$ Hb (g/dl). Note: linear range: 11–19 g/dl, absorbance change by 0.001 corresponds to haemoglobin concentration 0.02 g/dl; turbidity, manifesting itself in some measurements and leading to an apparent increase of haemoglobin concentration, is attributable to the loss of proteins, particularly macroglobulins.

In such a case, the absorbance measurements are taken after the turbidity is removed by intensive centrifugation or by adding one drop of NH_4OH (mmol/l). However, turbidity due to major hyperlipidaemia would not disappear after centrifuging or adding NH_4OH.

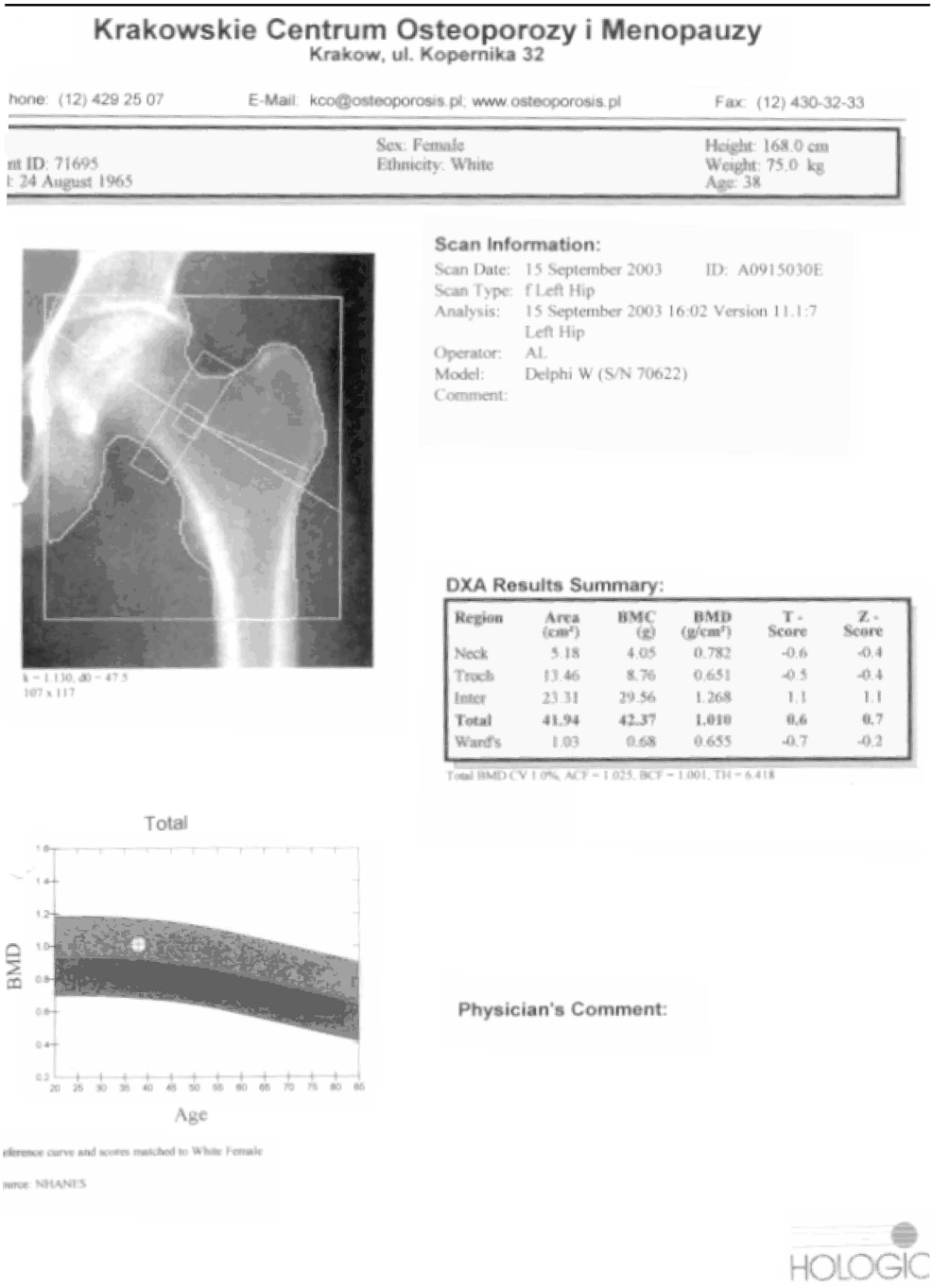
The tests for hemoglobin were performed with the use of EPOL 20 apparatus (it is a novel, microprocessor-controlled high-precision colorimeter, monochromatic radiation with quasi-double beam splitters ensure the high zero-point stability); monochromatic radiation is ensured by high-stability interference filters; twelve wavelengths are selectable, from the range 340–900 nm, the set of standard filters: 340, 405, 520, 540, 560, 630 nm; one-half transmission band < 8 nm; attenuation beyond the transmission band $> 10^5$; wavelength set accuracy ± 2 nm; absorbance range: 0–2500 j.A, measurement error: $\pm 1\%$ or 0.003 j.A over the whole range; absorbance zero point instability: < 0.005 j.A/hour and < 0.003 j.A/ hour, 15 minutes after switching on.

- Determination of acid-base equilibrium parameters in arterialised blood, utilising the Corning 238 apparatus. The following data were obtained:
  - molar concentration of H^+ ions with the accuracy of 0.1 mmol/l,
  - pCO_2-CO_2 pressure in blood (partial pressure of CO_2),
  - pO_2 – oxygen pressure in blood,
  - HCO_3 – bicarbonate buffer component,
  - tCO_2 – level of blood saturation with CO_2,
  - excess or shortage of buffering bases NZ,
  - $O_{2\mathrm{sat}}$ – level of blood saturation with oxygen.

The main purpose was to monitor the variations of acid-base equilibrium parameters after the training sessions.

Mineral density of bones was determined by the DXA method, using the DPX-IQ LUNAR apparatus. Measurements were taken in the AP projection (the DPX-IQ is an X-ray densitometer used for measurements of bone density at all skeletal sites; it utilises a high performance detector technology, an advanced flatbed scanner and is equipped with a radiation source X); fixed RTG lamp potential: 38/70 KeV, stability $\pm$ 0.05%, double energy beam 2×36 KeV collimated to the radius 0.01 m in diameter; the measurements are fast (lasting five seconds) and at a low radiation dose (up to 10 mR), an automatic calibration system brings the reproducibility error down to 0.52%, whilst the BMD measurement accuracy is less than 1%. Selected densitometric data are shown in Fig. 5.

The statistical analysis of test results was performed in accordance with the inference algorithm. The analysis was performed in the Statistica 5.0 environment. The choice of the statistical test was supported by the analysis of distributions of dependent variables. The t-Student test was performed. The zero hypothesis in every analysis was as follows: low-frequency vibrations exposure does not bring about the changes of a dependent variable. The significance level was taken as $p < 0.05$ (a typical value in e.g. biological sciences). Statistical analyses of the effects of low-frequency vibrations exposure on selected parameters of peripheral blood (acid-base equilibrium), haemoglobin



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nt ID: 71695
l: 24 August 1965
Sex: Female
Ethnicity: White
Height: 168.0 cm
Weight: 75.0 kg
Age: 38

k = 1.130, d0 = 47.5
107 x 117

Scan Information:
Scan Date: 15 September 2003 ID: A0915030E
Scan Type: f Left Hip
Analysis: 15 September 2003 16:02 Version 11.1:7
Left Hip
Operator: AL
Model: Delphi W (S/N 70622)
Comment:

DXA Results Summary:

Region	Area (cm^2)	BMC (g)	BMD (g/cm^2)	T - Score	Z - Score
Neck	5.18	4.05	0.782	-0.6	-0.4
Troch	13.46	8.76	0.651	-0.5	-0.4
Inter	23.31	29.56	1.268	1.1	1.1
Total	**41.94**	**42.37**	**1.010**	**0.6**	**0.7**
Ward's	1.03	0.68	0.655	-0.7	-0.2

Total BMD CV 1.0%, ACF = 1.025, BCF = 1.001, TH = 6.418

Total

BMD

Age

eference curve and scores matched to White Female

ource: NHANES

Physician's Comment:

HOLOGIC

Fig. 5. Densitometric data.

Table 1. Statistical analysis of biochemical and physiological parameters.

FRACTION OF DECREASE	VARIABLE	UNIT	AVERAGE	STANDARD DEVIATION	DIFFERENCE	t	p
0.46	$H^{+\,\mathrm{before}}$	nmol/l	40.1	1.72	−0.046	−0.082	0.9352
	$H^{+\,\mathrm{after}}$		40.1	1.30			
0.92	pCO_2^{before}	mmHg	43.0	3.39	3.153	5.588	**0.0001**
	pCO_2^{after}		39.8	2.67			
0.62	pO_2^{before}	kPa	68.5	9.67	3.846	1.722	0.1106
	pO_2^{after}		64.6	3.68			
0.85	HCO_3^{before}	nmol/l	26.5	1.56	1.985	5.754	**0.0000**
	HCO_3^{after}		24.5	1.08			
0.85	tCO_2^{before}	nmol/l	27.8	1.67	2.100	5.835	**0.0000**
	tCO_2^{after}		25.7	1.15			
0.85	NZ^{before}	nmol/l	1.9	1.36	3.931	5.317	**0.0001**
	pNZ^{after}		0.02	0.95			
0.85	$O_{2\mathrm{sat}}^{\mathrm{before}}$	%	93.7	2.11	0.7769	1.633	0.1283
	$O_{2\mathrm{sat}}^{\mathrm{after}}$		92.9	1.12			
0.85	Hb^{before}	g/dl	12.6	2.25	−2.900	−4.79	**0.0004**
	Hb^{after}		15.5	2.80			
0.77	PS^{before}	mmHg	113.8	6.53	1.735	2.34	**0.037**
	PS^{after}		112.0	7.18			
0.23	PR^{before}	mmHg	67.6	5.51	−0.635	−0.690	0.503
	PR^{after}		68.2	5.79			
0.54	T^{before}	°C	34.9	5.91	−1.63	−0.993	0.340
	T^{after}		36.6	0.12			
0.46	PD^{before}	s	16.3	1.79	−0.090	−0.408	0.689
	PD^{after}		16.4	1.89			

Legend: H^+ – molar concentration of hydrogen ions, PCO_2 – pressure of CO_2 in blood, HCO_3 – second component of bicarbonate buffer, $O_{2\mathrm{sat}}$ – level of blood saturation with oxygen, NZ – total sum of buffer anion concentrations in blood, Hb – haemoglobin concentration, PS – systolic pressure, PD – diastolic pressure, T – body temperature, PD – response time (Dietrich test), Fraction – index of structure of population expressed as the ratio of the number of population members sharing the given statistical feature to the size of the whole population.

Table 2. Significance of changes of oxygen saturation level and heart beat rate.

FRACTION OF INCREASING	VARIABLE	UNIT	AVERAGE	STANDARD DEVIATION	DIFFERENCE	t	p
0.07	SpO_2^{before}	%	96.7	0.98	0.095	0.41	0.686
	SpO_2^{after}		96.6	0.39			
0.69	HR^{before}	1/s	91.5	9.59	-1.690	-2.39	**0.033**
	HR^{after}		93.27	8.64			

Legend: SpO_2 – level of saturation with oxygen, HR – heart beat rate.

Table 3. Significance of densitometric data variations.

FRACTION OF INCREASING	VARIABLE	UNIT	AVERAGE	STANDARD DEVIATION	DIFFERENCE	t	p
0.82	BMC-Z ^{before}	g/cm^3	3.751	0.754	-0.0171	-1.06	0.311
	$BMC\text{-}Z^{after}$		3.768	0.761			
0.91	**BMD-Z**^{before}	g/cm^2	0.512	0.061	-0.058	-2.57	**0.026**
	BMD-Z^{after}		0.518	0.062			
0.73	$BMC\text{-}T^{before}$	g/cm^3	-0.275	0.772	-0.0250	-0.82	0.429
	$BMC\text{-}T^{after}$		-0.250	0.759			
0.82	**BMD-T**^{before}	g/cm^2	-0.641	0.812	-0.1000	-2.57	**0.026**
	BMD-T^{after}		-0.541	0.828			

concentration and physiological parameters are summarised in Table 1. The effects of vibrations on oxygen saturation levels and the heart beat rates are shown in Table 2.

It is readily apparent (see Table 1) that low-frequency vibrations exposure produces statistically significant changes in the human body (significance level $p < 0.01$) in terms of: CO_2 pressure in blood (pCO_2), second components of the HCO_3 buffer, level of blood saturation with CO_2 and the total sum of anion concentrations. On the other hand, the exposure to vibrations does not change the molar concentration of hydrogen ions H^+, CO_2 pressure in blood and the level of blood saturation with oxygen.

Statistical analysis of densitometric data reveals that exposure to low-frequency vibrations brings about a statistically significant increase of the BMD-Z and BMD-T indices (Table 3).

4. Conclusions

The experimental data supported by statistical analyses reveal the following changes in peripheral blood parameters (controlling the acid-base equilibrium):

- CO_2 pressure (pCO_2) went down from 43 ± 3.391 to 39.84 ± 2.672 mm Hg in 92% of test participants,

- the second component of the bicarbonate buffer went down from 26.51 ± 1.566 to 24.53 ± 1.085 mmol/l in 85% of test participants,
- the sum total of buffer anion concentrations in blood fell down from 1.95 ± 1.363 to 0.02 ± 0.959 in 85% of test participants,
- the level of blood saturation with carbon dioxide fell down from 27.89 ± 1.672 to 25.79 ± 1.115 in 85% of participants.

Biochemical analyses revealed a major increase in haemoglobin concentration, which went up from 12.66 ± 2.256 to 15.56 ± 2.806 g/dl in 85% of the test group.

Statistical analysis of physiological data reveals:

- decrease of systolic pressure from 113.81 ± 6.533 to 112.07 ± 7.189 mm Hg in 77% of the test group,
- the pulse rate in 69% of participants went up from 91.58 ± 9.594 to 93.27 ± 8.646 l/s.

Statistical analysis of densitometric data reveals the exposure to low-frequency vibrations bringing about major statistically significant changes of:

- BMD-Z (from 0.512 ± 0.061 to 0.518 ± 0.062 g/cm^2) in 91% of the test group,
- BMD-T (from -0.641 ± 0.812 to -0.541 ± 0.828 g/cm^2) in 82% of participants.

The analysis of acid-base equilibrium parameters and the tendencies in their variability seem to confirm the view that exposure to low-frequency vibrations is perceived by the human body as a physical exercise. An increase of haemoglobin level reported in 85% of the test participants is suggestive of potential applications of low-frequency vibrations in the treatment of anaemia.

An increase in densitometric parameters BMD-Z (rising fraction 0.91) and BMD-T (fraction 0.82) indicates that low-frequency vibrations might be applied as a part of osteoporosis treatment.

The experimental and statistical data ought to be treated now as results of pilot tests only, whilst further systematic research is necessary. This programme was a part of the research project 3 T11E 006 26, supported by the Kościuszko Foundation and the American Centre for the Polish Culture through the funds granted by the Alfred Jurzykowski Foundation.

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