Sex differences in oxidative stress after eccentric and concentric exercise

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ABSTRACT

Objectives: Comparison of redox balance changes in the blood of women and men as a result of submaximal eccentric (ECC) and concentric (CONC) efforts.

Methods: 10 women and 10 men performed three 45-minute submaximal treadmill runs at constant velocities (downhill run – ECC, uphill run – CONC and level run). Prior to the 45-minute exercises, after their completion and following 24 hours of recovery, the concentration of lactate, oxidized low-density lipoprotein (ox-LDL), 3-nitrotyrosine, uric acid (UA) and the white blood cell count (WBC), neutrophil (NEUT), lymphocyte (LYMPH) and monocyte content in the blood were determined.

Results: In women, the ox-LDL increased significantly 10 minutes and 24 hours following ECC ($P < 0.05$). 10 minutes after ECC, in women, there was an increase in WBC, NEUT and LYMPH ($P < 0.05$). In the men, WBC and NEUT increased significantly 24 hours after CONC and ECC ($P < 0.05$). UA in each determination was higher in the men than the women ($P < 0.05$).

Discussion: ECC cause impaired redox balance only in women. Due to the increase in antioxidant capacity of the blood without accompanying oxidative damage to macromolecules, for both sexes, it is recommended to perform concentric running efforts at the highest possible subliminal intensity.

KEYWORDS

Oxidative stress; muscle damage; sex differences; eccentric exercise; concentric exercise; submaximal exercise

Introduction

Regular physical activity, chosen correctly in terms of intensity, duration and frequency of exercise and the type of muscle work, brings human health beneficial effects. It leads to, among others, improved cardiovascular efficiency, respiratory, metabolic and body composition changes [1,2].

Physical exercise can also have a negative effect on cells causing systemic oxidative stress, which is the result of an imbalance between the level of antioxidants (non-enzymatic of low and high molecular weight and antioxidant enzymes, together decisive of the total antioxidant capacity – TAC), and the level of reactive oxygen and reactive nitrogen species. Excessive production of free radicals during muscle work may be the result of the intensified metabolism of energy substrates and the activation of the leucocyte system [3–5]. Among the white blood cells, the most numerous occurring neutrophils are the main location of reactive oxygen species formation (respiratory burst), which is important in the process of microorganism inactivation. As it is apparent from the review of studies, neutrophil activation during exercise depends on the time, intensity and type of muscle work [6].

The consequence of large redox homeostasis disturbances is impaired intra- and intercellular signaling controlled by redox processes and/or damage to molecules by reactive oxygen and reactive nitrogen species [7,8]. The degree of redox homeostasis disturbances depends on, among others, the duration and intensity (the engaged energy system) of the effort, and may be different in men and women [4,9].

Previous studies have shown that efforts at maximal and supramaximal intensity cause systemic oxidative stress in women and men [10,11]. After performing an effort at maximal intensity, men showed a significant increase in total oxidative status (TOS), with no changes of TAC in the blood plasma [9]. The opposite relationship was found in women, i.e. only small changes of TOS levels in the blood plasma occurred after exercise, which were due to increasing antioxidant capacity [9]. In other study, it has been shown that the increase in TAC levels in women after exercise at maximal intensity was correlated with the level of muscle damage indicators in the blood serum (creatine kinase activity and lactate dehydrogenase activity) [11]. The level of oxidative damage to the lipids (oxidized low-density lipoprotein) and proteins (3-nitrotyrosine) was similar in men and women following exercise at maximal intensity [11]. In men, a positive correlation was found between the intensity of oxidative processes and the increase in lactate concentration of the blood as a result of the severity of anaerobic metabolism in an effort at maximal intensity [9]. In the case of similar acid–base balance disturbances, similarly in men and women, anaerobic exercise causes significant changes to TAC and TOS as well as changes in the concentration of low-molecular non-enzymatic antioxidants, which are evidence of post-exercise oxidative stress [10]. Karabulut [12], comparing the change in indicators of oxidative stress in men and women immediately after anaerobic exercise, noted an increase in the concentration of malondialdehyde as a product of oxidative damage to lipids and a decrease in the concentration of glutathione (GSH) – low-molecular antioxidant – only in men, with no significant differences in the values of the analyzed indicators in women.

Submaximal concentric and eccentric efforts elicit different physiological responses of the system [13,14]. The exercises at submaximal intensity can cause disruption of redox homeostasis, and the size of disorders depends on the duration of an exercise and the type of the muscle work – concentric (CONC) or eccentric work (ECC) [15–22]. In our opinion, the
The aim of our study was to assess the impact of submaximal exercise differing in type of muscle work (uphill running–concentric work and downhill running–eccentric work) on the balance of redox processes in the blood of women and men, evaluated on the basis of the concentration of lipid oxidation products [24], nitrosoylation of proteins [25] and uric acid, as part of non-enzymatic antioxidant defense [26].

Material and methods

Participants

Twenty healthy, recreationally active (light to moderate exercise ≥3 times per week) physical education students (10 men 22.3 ± 0.5 years old and 10 women 20.6 ± 0.4 years old), not involved in competitive sports, participated in the study.

The study was conducted in accordance with the methods approved by the Bioethical Committee of the Regional Medical Chamber (88/KBL/OIL/2010). The participants were informed about the purpose and course of the study, and written informed consent for voluntary participation in the study was obtained.

Prior to the stress test, participants underwent medical procedure qualification and were acquainted with the laboratory conditions as well as the measurement tools and the way to prepare for following stages of testing. The women had regular menstrual cycles, verified by measuring basal body temperature and determinations of estradiol and progesterone in the blood, and took no hormonal medication. The exercise tests were carried out under medical supervision. Each of the participants performed a total of four running stress tests: a graded test and three 45-minute efforts of submaximal intensity, differing in the type of performed muscle work. On the first day of testing, somatic measurements and the graded test were performed. Seven days after the graded test, the first of the three submaximal intensity efforts was performed (starting in random order), maintaining a 14-day interval between them. The somatic measurements and stress tests were performed in the morning (8.00–11.30 a.m.) in a similar ambient temperature (20–22°C). The dates of the following tests were selected while maintaining the same testing time for the given participant. The subjects got at least 8 hours of rest the night before the test, ate a light meal no earlier than 2 hours prior testing and were properly hydrated.

Participants did not carry out any intense physical efforts and did not consume alcohol, caffeine, other stimulants or nutritional supplements for at least 48 hours prior to the performance of the exercise tests or 24 hours after their completion.

Somatic measurements

Body height (BH) was measured to the nearest 1 mm (Martin-type anthropometer, U.S.A), body mass (BM) using Tanita TBF-300 (Japan). Fatty skin-folds were measured at three points on the left side of the body: the triceps, under the lower angle of the shoulder blade and halfway between the navel and the anterior superior iliac spike. Skin-folds were measured using the caliper method to the nearest 0.1 mm (Harpenden-type skin-fold caliper). On the basis of skin-folds, using the formula by Durnin and Womersley [27], we assessed the density of the body, and on its basis, the percentage of body fat in the total body mass (PBF) [28], lean body mass (LBM) and fat mass (FM). Body mass index (BMI) was calculated for each person. Somatic characteristics of the participants are shown in Table 1.

Stress tests

Graded test

The test (angle of 0°, h/p/Cosmos Saturn COS 10198 treadmill, Germany) started with a 4-minute effort at 7 km h⁻¹ for men and 6 km h⁻¹ for women. Subsequently, running speed was increased every 2 minutes (by 1.2 km h⁻¹ in men and 1.0 km h⁻¹ in women), until exhaustion or lack of increase in oxygen consumption despite the increase in running speed.

Starting 2 minutes before exercise and until its completion, we recorded (Medikro 919 ergospirometer, Kuopio, Finland) averaged values of respiratory indicators over 30-second long periods: oxygen uptake (VO₂), carbon dioxide production (VCO₂), pulmonary ventilation (VE), expiratory carbon dioxide concentration (%FECO₂), respiratory exchange ratio (RER) and ventilatory equivalent ratio for carbon dioxide (VE/VCO₂).

Heart rate (HR) was recorded at 5-second intervals (Polar S610i heart rate monitor, Kempele, Finland).

During the test, the maximal oxygen uptake per minute (VO₂max), maximum heart rate and second ventilatory threshold (respiratory compensation point – RCP) were determined. The maximal and at RCP values of physiological parameters are shown in Tables 2 and 3.

We adopted the following criteria for attaining VO₂max [29]:

1. a plateau in oxygen uptake,
2. RER > 1.1,
3. attainment of a heart rate within 10 beats per minute of the age-predicted maximum.

Where no plateau in oxygen uptake was observed but the rest of the criteria were met, VO₂ peak was taken as VO₂max [30]. Maximal oxygen uptake relative to body mass (VO₂max BM⁻¹) and relative to lean body mass (VO₂max LBM⁻¹) was calculated.

RCP as defined as the exercise intensity at which the following conditions were simultaneously met [31,32]:

1. decrease in %FECO₂ after reaching maximal level,
2. rapid nonlinear increase in VE (second deflection),
3. VE/VCO₂ ratio reached minimum and began to increase,
4. rapid nonlinear increase in VCO₂ (second deflection).

Submaximal exercises

Each participant performed, in random order, three 45-minute submaximal efforts at a constant speed (h/p/Cosmos Saturn COS 10198 treadmill, Nussdorf-Traunstein Germany) corresponding to the intensity of 50–55%VO₂max (6.92 ± 0.25 km h⁻¹ for men, 5.34 ± 0.14 km h⁻¹ for women). In order to avoid changes in the level of physiological and biochemical response resulting from changes in the form of movement at a constant speed of locomotion [33], we assumed the form of a run for all the tests. During the first...
30 minutes of the exercise, the run was performed at level, while for the last 15 minutes of the exercise, the slope angle of the treadmill was changed (only during the run at level speed remain steady). An intensity of about 50% VO2max was chosen because during the level running, the steady state should be observed [34].

In order to minimize the potential drift of oxygen during the downhill run, the exercise duration was only 15 minutes after changing the slope angle [35]. Therefore, the participants performed three exercises differing in type of muscle work in the last 15 minutes of running:

1. **LEVEL**: 45 minutes, 0° inclination angle;
2. **CONC**: 30 minutes, 0° inclination angle, 15 minutes of uphill running + 4.5° angle, concentric work;
3. **ECC**: 30 minutes, 0° angle, 15 minutes of downhill running − 4.5° angle, eccentric work.

The intensity of the various types of efforts, expressed as % VO2max, is not significantly different in women than the men, and amounted to LEVEL: 53.9 ± 8.7 and 50.3 ± 4.0%VO2max, CONC: 76.0 ± 6.8 and 72.4 ± 3.0%VO2max, ECC: 39.7 ± 9.4 and 37.9 ± 5.2%VO2max, respectively. We analyzed the mean value of VO2 during the last 10 minutes of each exercise (5 minutes after changing the angle in the CONC and ECC) after reaching steady state [34].

In addition, the women started to randomly perform tests in mid-follicular or mid-luteal phases, which depended on the course of their current menstrual cycle.

Biochemical determination

Venous blood was collected from the antecubital vessels (BD Vacutainer vacuum system, Franklin Lakes, NJ, U.S.A), 10 minutes prior to submaximal efforts, 10 minutes and 24 hours after their completion, always after 5 minutes spent in a seated position. Two milliliters of blood was collected into tubes containing coagulation activators, which after 20 minutes of clotting at room temperature were centrifuged at RCF 14,300 × g for 15 minutes at 4°C (MPW 55, Warsaw, Poland), and the obtained serum was stored at a temperature of −20°C until the time of determination. We did not note hemoysis or lipemia in any of the samples. Two milliliters of blood was collected into tubes containing EDTA as an anticoagulant.

As an index of oxidative damage to lipids and protein nitrosylation, we determined the appropriate concentration of oxidized low-density lipoprotein (ox-LDL) and the concentration of 3-nitrotyrosine (3-NT) in the serum. As an antioxidant, the concentration of uric acid (UA) was determined in the blood serum.

The concentration of ox-LDL and 3-NT were determined by enzyme immune assay tests using the K7810 and K7824 Immundiagnostik test (Bensheim, Germany), respectively. The assays use the ‘sandwich’ technique with two polyclonal antibodies. The concentrations of ox-LDL and 3-NT were automatically read from the calibration curves made under tube analysis conditions. The accuracy of the results was verified on the basis of the readings of trial control concentrations included in the reagent kits. UA concentration was determined by the enzymatic colorimetric method using the Uric Acid Randox test (Crumlin, UK).

Using fluorescence flow cytometry (Sysmex XT-2000i, Japan), the concentration of hemoglobin (HGB), hematocrit (HCT), the total leukocytes (WBC) and the content of: neutrophils (NEUT), lymphocytes (LYMPH) and monocytes (MONO) were determined in the whole blood.

In order to determine the lactate concentration, 5 minutes before and immediately after the submaximal efforts, 300 µL of capillary blood was collected from the fingertip and put into tubes containing EDTA as the anticoagulant and sodium fluoride as a glycolysis inhibitor. The blood was stored on ice for no longer than 20 minutes, and centrifuged for 3 minutes at RCF 14,300 × g (MPW 55, Warsaw, Poland). Immediately after centrifugation, 10 µL was collected and assayed for plasma lactate concentration by colorimetric assay using L-Lactate Randox enzymatic test (Crumlin, UK).

The absorbance was measured using the DRG E-lysis MAT 3000 (DRG Int., Springfield, NJ, U.S.A) and the UV/Vis Evolution 201 ThermoScientific (Milwaukee, Wisconsin, U.S.A).

The concentrations of ox-LDL, 3-NT, UA, lactate and the contents of WBC, NEUT, LYMPH and MONO were altered according to the formula by Kraemer and Brown [36] by the percentage changes in plasma volume calculated on the basis of changes in HGB and HCT [37,38] occurring 10 minutes and 24 hours after the submaximal effort compared to the values from before the effort.

Statistical analysis

Data distribution was checked with the Shapiro–Wilk test. The significance of inter-sex differences for single measurements, depending on the distribution of the variables, was assessed using the t test for independent variables or the Mann–Whitney U test. To compare the influence of the exercise type (LEVEL, CONC, ECC) on changes in the level of biochemical and hematological indicators, we used two-factor (effort, time) analysis of variance with repeated measurements (MANOVA) separately in the group of women and men. To compare the inter-sex differences in post-exercise changes of the indicators analyzed according to the type of exercise, we performed three-factor (sex, effort, time) analysis of variance with repeated measurements (MANCOVA), taking the dependency of these indicators on VO2max and/or exercise intensity expressed as %VO2max into account in the statistical analysis, for which there were significant differences between genders or differences depending on the type of effort. In the case that the main factor was considered significant, we examined the

**Table 1.** Somatic characteristics of study participants (mean ± SE)

|            | Age (years) | BH (cm)   | BM (kg) | LBM (kg) | FM (kg) | PBF (%) | BMI (kg m⁻²) |
|------------|-------------|-----------|---------|----------|---------|---------|--------------|
| Women      | 20.6 ± 0.4  | 164.7 ± 1.0 | 55.3 ± 2.0 | 43.2 ± 0.8 | 12.1 ± 41.3 | 21.3 ± 1.6 | 20.4 ± 0.7  |
| Men        | 22.3 ± 0.5  | 182.7 ± 1.6 | 80.9 ± 2.0 | 67.1 ± 1.3 | 13.8 ± 1.2 | 16.9 ± 1.1 | 24.2 ± 0.5  |
| P value    | 0.02        | <0.01      | <0.01   | <0.01    | 0.34    | <0.01   | <0.01        |

P < 0.05 statistically significant differences men vs. women; BH: body height; BM: body mass; LBM: lean body mass; FM: fat mass; PBF: percentage of body fat; BMI: body mass index.
significance of differences between specific averages using post hoc analysis (Tukey test). Correlations between the level of pre- and post-exercise changes in biochemical indicators, and VO2max and %VO2max respectively, were determined using Pearson’s test. For all variables, differences in means were considered as statistically significant at the level of P < 0.05. All data are presented as mean ± SE. Calculations were performed using Statistica 10 (Stat-Soft, Inc., Tulsa, OK, U.S.A).

Results

In women, there was no significant effort and time effect for ox-LDL but a significant effort/time interaction effect occurred (F = 2.64, P = 0.04). Ten minutes and 24 hours after the completion of ECC, we noted a significant increase in the concentration of ox-LDL in the blood serum of women by 59.4 and 87.8%, respectively, as compared to the value before exercise (post hoc analysis) (Table 4). No significant effort, time or interaction effects were observed for the concentration of 3-NT or UA in the serum of men. In both groups, there was a significant effort, time and effort/time interaction effect for lactate concentration (respectively, F = 15.01, P < 0.01; F = 26.29, P < 0.01; F = 19.76, P < 0.01 in women and, F = 11.85, P < 0.01, F = 3.84, P = 0.06; F = 15.32, P < 0.05 in men). Post hoc analysis revealed that lactate concentration in the blood plasma significantly increased in both groups after completion of the concentric exercise (CONC) (Table 4).

Analyzing the inter-gender differences in the level of biochemical indicators revealed a significant influence of gender (F = 7.45, P = 0.01), but only on the concentration of UA in the blood plasma. Serum UA concentration was higher for men than women in each assay (Table 4). No gender related differences in post-exercise changes of UA, 3-NT or lactate concentrations were found with regard to type of exercise (no significant sex/effect/time interaction effect). There was a significant sex/effect/time interaction effect for ox-LDL concentration (F = 4.90, P = 0.03).

In men, there was a significant time effect for the content of WBC (F = 29.88, P < 0.01), NEUT (F = 12.92, P < 0.01) and, LYMPH (F = 32.88, P < 0.01) in the blood. Post hoc analysis revealed that, the content of WBC, NEUT and LYMPH in the blood of women significantly increased 10 minutes after ECC, but a significant effort/time interaction effect was found for WBC (F = 3.48, P = 0.01) and LYMPH (F = 6.66, P < 0.01). In men, there was a significant time effect for the content of WBC (F = 21.04, P < 0.01), NEUT (F = 20.59, P < 0.01), LYMPH (F = 12.51, P < 0.01) and MONO (F = 5.53, P = 0.01). Post hoc analysis showed that, there was a significant increase in WBC and NEUT in the blood of men 24 hours after CONC and ECC. There was no significant effort/time interaction effect for hematological indicators in men (Table 5). Analyzing the gender related differences in the level of hematological indicators we found significant influence of gender on the content of WBC (F = 4.48, P = 0.04), NEUT (F = 5.84, P = 0.02) and MONO (F = 24.31, P < 0.01). The results of post hoc analysis are presented in Table 5. Significant inter-gender differences were found in LYMPH changes depending on the type of exercise (sex/effect/time interaction effect F = 2.65, P = 0.04).

In the group of men, we found a positive correlation between the pre-exercise concentration of UA in the serum and VO2max (r = 0.47, P = 0.01). A positive correlation was noted between the change in UA and lactate concentration after the effort and the intensity of the exercise (%VO2max); correlation coefficients equally r = 0.51 (P < 0.01) and r = 0.65 (P < 0.01), respectively, in the group of women and r = 0.40 (P = 0.03) and r = 0.73 (P < 0.01) in the group of men.

Discussion

Our study shows that there are gender differences in terms of changes in redox balance as a result of performing different types of submaximal physical efforts engaging various types of muscle work (eccentric, concentric work). In the group of women, as a result of the eccentric work, we found an increase in the concentration of ox-LDL, testifying to the oxidative damage of lipids, which was accompanied by an increase in the number of neutrophils and lymphocytes in the blood. Regardless of the type of muscle work, submaximal efforts did not result in significant changes in the level of oxidative stress indicators in men, despite changes indicative of neutrophil activation.

In a previous study, it was found similar redox imbalances in both sexes which involved an increase in the concentration of protein carbonyls, oxidized glutathione (GSSG) and malondialdehyde after 30 minutes of running at submaximal intensity at the level, corresponding to 80%VO2max [17]. Bloomer et al. [16] showed that after 30 minutes, the effort on the cyclergometer at an intensity of 70% VO2max causes a significant and, at the same time, similar increase in the concentration of protein carbonyls in both men and women, which is indicative of oxidative protein damage. Extending the effort time to 60 and 120 minutes causes

### Table 2. Maximal values of physiological indicators in study participants (mean ± SE)

|                          | VO2max (L min⁻¹) | VO2max BM⁻¹ (mL kg⁻¹ min⁻¹) | VO2max LBM⁻¹ (mL kg⁻¹ min⁻¹) | Vimax (L min⁻¹) | HRmax (b min⁻¹) |
|--------------------------|------------------|-----------------------------|-------------------------------|----------------|-----------------|
| Women                    | 2.47 ± 0.11      | 44.73 ± 1.23                | 56.95 ± 1.85                  | 85.1 ± 2.8      | 195.9 ± 3.1     |
| Men                      | 4.76 ± 0.34      | 59.16 ± 1.55                | 70.93 ± 1.47                  | 150.4 ± 5.7     | 197.2 ± 2.5     |
| P value                  | <0.01            | <0.01                       | <0.01                         | <0.01          | 0.62            |

P < 0.05 statistically significant differences men vs. women; VO2max: maximal oxygen uptake; Vimax: maximal pulmonary ventilation; HRmax: maximal heart rate.

### Table 3. Threshold (RCP) values of physiological indicators in study participants (mean ± SE)

|                          | VO2 (L min⁻¹) | VO2-BM⁻¹ (mL kg⁻¹ min⁻¹) | VO2-LBM⁻¹ (mL kg⁻¹ min⁻¹) | HR (b min⁻¹) | Exercise intensity at RCP |
|--------------------------|---------------|--------------------------|----------------------------|--------------|---------------------------|
|                          |               |                          |                            |              | %VO2max          | %HRmax          |
| Women                    | 1.93 ± 0.14   | 34.59 ± 1.48             | 44.36 ± 2.57               | 176.7 ± 3.5  | 79.3 ± 1.8        | 90.1 ± 1.0      |
| Men                      | 3.76 ± 0.20   | 46.34 ± 1.69             | 55.93 ± 2.54               | 174.1 ± 3.2  | 78.3 ± 2.1        | 88.0 ± 1.4      |
| P value                  | <0.01         | <0.01                    | <0.01                      | 0.59         | 0.72             | 0.24            |

P < 0.05 statistically significant differences men vs. women; RCP: respiratory compensation point; VO2: oxygen uptake at RCP; HR: heart rate at RCP.
increases in the concentration of protein carbonyls, and the protein carbonyls peak level was correlated in both groups with the volume of the performed work [16]. In another study among men performing (every 12 minutes) 5-minute cycling efforts at an intensity of 40, 55, 70, 85 and 100% VO₂max, it was found that an increase in exercise intensity above 70% VO₂max causes significant, systematic increases in biological antioxidant potential above the output level. In contrast, increasing reactive oxygen metabolites was only noted following efforts at an intensity of 85%VO₂max [22]. In the study by Diaz et al. [19], submaximal graded exercise performed at an intensity of up to 75–80% of heart rate reserve for women and men caused an increase in the activity of superoxide dismutase and TAC without changes in biomarkers of oxidative damage to lipids and proteins. In these studies, however, inter-sex differences were not taken into account [19].

The research by Balci et al. [33] demonstrated that lipid peroxidation is greater when walking at a speed corresponding to the walk-to-run transition in comparison to running performed at the same speed, accompanied by higher levels of physiological stress responses (oxygen uptake, carbon dioxide output, heart rate) and energy expenditure during walking. At the same time, both efforts resulted in an increase of catalase activity in the blood of men. The application, as in our study, of efforts involving uphill (concentric work) and downhill running (eccentric work) at a constant speed and at the same slope angles, respectively, leads to an increase or reduction in the level of physiological reactions (VE, VO₂, HR) and work intensity compared to level running.

Such changes can result from the activation of neutrophils as a result of sarcolemma microdamage and increased reactive oxygen species synthesis by these cells (oxidative/respiratory burst) [39]. However, noted were both an increase in neutrophil oxidative burst activity after efforts causing damage to myocytes [40], as well as no changes in this indicator despite the significant increase in the content of neutrophil oxidative burst activity after efforts causing damage to myocytes [40].

In our study, both men and women performed physical exercises differing in the type of dominant muscle work, but at similar intensities in both groups, and for each type of effort, the intensity corresponding to below or equal to the RCP. In our study, oxidative damage to lipids was dependent on the type of muscle work in women. The increase in the concentration of ox-LDL in the blood of women was caused by the walk-to-run transition in comparison to running at similar intensities in both groups, and for each type of effort, the intensity corresponding to below or equal to the RCP. In our study, oxidative damage to lipids was dependent on the type of muscle work in women. The increase in the concentration of ox-LDL in the blood of women was caused by the walk-to-run transition in comparison to running at similar intensities in both groups, and for each type of effort, the intensity corresponding to below or equal to the RCP. In our study, oxidative damage to lipids was dependent on the type of muscle work in women.
exercise may be the result of not only excessive ROS synthesis but also insufficient antioxidant defense. In our study, we found that the level of UA which performs an antioxidant role is lower both before the effort as well as after the exercise in the group of women. That is why the lack of oxidative lipid changes in the blood of men after eccentric exercise, compared to the increased concentration of ox-LDL in women, can result from higher levels of uric acid, which increases the antioxidant capabilities of the body in men depen-
dent on higher physical capacity. Due to the increase in antioxid-
ant enzyme activity: superoxide dismutase, catalase, glutathione peroxidase and reductase, GSH levels and the level of lipid peroxidation) did not depend on the day of the menstrual cycle. The women in our study randomly performed various submaximal efforts in the follicular or luteal phase of their menstrual cycle and did not repeat each of the submaximal efforts in two phases of the menstrual cycle. Therefore, we did not compare the possible effects of menstrual cycle hormones on the post-exercise reactions regarding redox homeostasis in women [43]. We also did not examine the possible genetic factors that could influence muscle damage during eccentric exercise and changes in redox balance [44].

Conclusions

Despite the lower intensity compared to concentric work, submaximal eccentric running efforts cause oxidative damage to lipids in women, which indicates impaired redox balance. In men, regardless of the type of muscle work (eccentric, concentric), submaximal running efforts do not cause oxidative stress. The probable cause of these inter-sex differences is the greater antioxidant potential of the blood in men dependent on higher physical capacity. Due to the increase in antioxidant capacity of the blood without accompanying oxidative damage to macromolecules, for both sexes, it is recommended to perform concentric running efforts at the highest possible subliminal intensity.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National Science Centre (Poland) under Grant number N N404 071240 and by the University of Physical Education in Krakow (Poland) under Grant number 267/IFC/2010.

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Table 5. Hematological indicators contents in the blood before and after concentric (CONC) and eccentric (ECC) work and level running in women and men (mean ± SE)

| Variable     | Time         | Level (0°) | CONC (+4.5°) | ECC (−4.5°) | Effort | Time | Effort/time |
|--------------|--------------|------------|--------------|-------------|--------|------|-------------|
| WBC (10³ µL⁻¹) | Before      | 6.67 ± 0.70 | 6.05 ± 0.51 | 6.17 ± 0.68 | 0.40   | 29.88 | 3.48        |
|              | After        | 7.24 ± 0.73 | 6.87 ± 0.73 | 8.52 ± 0.63 | (0.70) | (<0.01) | (0.01)     |
|              | 24 hours after | 6.09 ± 0.80 | 5.58 ± 0.37 | 5.98 ± 0.57 |        |      |            |
| NEUT (10³ µL⁻¹) | Before      | 4.16 ± 0.54 | 3.88 ± 0.48 | 3.66 ± 0.52 | 0.08   | 12.92 | 0.96        |
|              | After        | 4.52 ± 0.56 | 4.30 ± 0.62 | 4.87 ± 0.58 | (0.92) | (<0.01) | (0.44)     |
|              | 24 hours after | 3.75 ± 0.58 | 3.42 ± 0.26 | 3.51 ± 0.40 |        |      |            |
| LYMPH (10³ µL⁻¹) | Before      | 2.15 ± 0.18 | 1.82 ± 0.10 | 2.13 ± 0.19 | 3.26   | 32.88 | 6.66        |
|              | After        | 2.26 ± 0.18 | 2.19 ± 0.09 | 3.14 ± 0.21 | (0.06) | (<0.01) | (0.01)     |
|              | 24 hours after | 1.92 ± 0.18 | 1.76 ± 0.11 | 2.05 ± 0.19 |        |      |            |
| MONO (10³ µL⁻¹) | Before      | 0.19 ± 0.02 | 0.15 ± 0.01 | 0.18 ± 0.04 | 1.00   | 1.77  | 0.68        |
|              | After        | 0.21 ± 0.04 | 0.18 ± 0.02 | 0.26 ± 0.03 | (0.38) | (0.18) | (0.61)     |
|              | 24 hours after | 0.20 ± 0.03 | 0.18 ± 0.03 | 0.18 ± 0.02 |        |      |            |
| Men WBC (10³ µL⁻¹) | Before      | 4.71 ± 0.32b | 5.19 ± 0.27 | 4.71 ± 0.35 | 1.00   | 21.04 | 0.61        |
|              | After        | 5.18 ± 0.38b | 6.23 ± 0.42 | 5.17 ± 0.43 | (0.38) | (<0.01) | (0.66)     |
|              | 24 hours after | 6.17 ± 0.56 | 6.97 ± 0.50b | 6.81 ± 0.88 |        |      |            |
| NEUT (10³ µL⁻¹) | Before      | 2.71 ± 0.31b | 2.96 ± 0.18 | 2.76 ± 0.24 | 0.53   | 20.59 | 0.82        |
|              | After        | 2.87 ± 0.31b | 3.39 ± 0.29 | 2.95 ± 0.29a | (0.59) | (<0.01) | (0.52)     |
|              | 24 hours after | 3.51 ± 0.39 | 3.93 ± 0.24a | 4.10 ± 0.52a |        |      |            |
| LYMPH (10³ µL⁻¹) | Before      | 1.74 ± 0.9 | 1.98 ± 0.12 | 1.69 ± 0.17 | 2.77   | 12.51 | 0.37        |
|              | After        | 2.01 ± 0.10 | 2.56 ± 0.13b | 1.98 ± 0.14b | (0.08) | (<0.01) | (0.83)     |
|              | 24 hours after | 2.31 ± 0.19 | 2.66 ± 0.24b | 2.36 ± 0.34 |        |      |            |
| MONO (10³ µL⁻¹) | Before      | 0.09 ± 0.02b | 0.12 ± 0.02 | 0.10 ± 0.02 | 0.45   | 5.53  | 0.62        |
|              | After        | 0.13 ± 0.01b | 0.15 ± 0.03 | 0.11 ± 0.01b | (0.64) | (0.01) | (0.65)     |
|              | 24 hours after | 0.17 ± 0.01 | 0.15 ± 0.02 | 0.14 ± 0.02 |        |      |            |

*After exercise vs. before exercise.
Men vs. women; WBC: white blood cells; NEUT: neutrophils; LYMPH: lymphocytes; MONO: monocytes.
Significant differences (P < 0.05).
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