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Original Research Article

Gender differences in residual effect of prior drop jumps on oxygen uptake during heavy cycling exercise

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ABSTRACT

Background and objective: Unaccustomed eccentric or eccentric–concentric exercise leaves us stiff and sore the next day and can cause muscle damage. The data about the residual effect of prior eccentric–concentric exercises on oxygen uptake (VO_2) during constant cycling exercise in women or the data about differences of such effect between genders are scarce. Therefore, the aim of this study was to assess differences of the residual effect of PDJ on VO_2 during HCE and indirect muscle damage parameters between women and men.

Materials and methods: The study aimed to asses differences of the residual effect of prior drop jumps (PDJ) on VO_2 during heavy cycling exercise (HCE) and indirect muscle damage parameters between men ($n = 8$) and women ($n = 11$). On four different days participants performed one incremental cycling exercise and three HCE (control [CON], 45 min [45′ PDJ] and 24 h [24 h PDJ] after 100 drop jumps). The intensity of HCE was set to work rate corresponding to 50% of the difference between the second and the first ventilatory thresholds which were determined analyzing pulmonary gas exchange parameters during incremental cycling exercise. Capillary blood samples were collected in order to measure blood lactate concentration immediately after HCE and serum creatine kinase (CK) activity 24 h after PDJ. Subjects rated perceived exertion and delayed onset muscle soreness (DOMS) using 20 and 10 point scales, respectively.

Results: VO_2 at 3–6 min of HCE performed 45′ after PDJ was significantly increased as compared to CON HCE only in the male group. Both men and women felt moderate muscle pain. CK activity was significantly increased 24 h after PDJ in the male group. Both during HCE 45′ PDJ and 24 h PDJ, the significant positive correlation was observed between relative changes of VO_2 during steady state of HCE and CK activity only in the male group.

Conclusions: Prior eccentric–concentric exercise of thigh muscles (100 drop jumps) accelerates VO_2 kinetics at the start and increases VO_2 during steady state of heavy cycling only in

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the male group. So, prior exercise of such type has a higher negative impact on cycling economy in men than in women and this might be related to greater muscle damage and fatigue in physically active male persons after plyometric exercise.

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1. Introduction

It is well established that unaccustomed eccentric or eccentric–concentric exercise leaves us stiff and sore the next day and can cause muscle damage. Muscle damage is characterized by delayed onset muscle soreness (DOMS), muscle fiber disarrangement and inflammatory cell infiltration, increased serum creatine kinase (CK) activity, decreased muscle force production, and decreased concentric contraction performance efficiency [1,2]. Repetitive prior drop jumps (PDJ) from 0.4 to 0.5 m height induce long lasting (within 24–48 h of recovery) muscle fatigue with concomitant signs of muscle damage [3].

The data about gender differences in exercise induced muscle damage are contradictory. The CK activity and DOMS rating have been found both similar [4] or higher in women [5] or in men [6] during different periods after eccentric–concentric exercise. The decrease in elbow flexors maximal voluntary force has been similar in women and men after eccentric exercise [7]. In contrast, a larger leg strength decrease has been observed in women at 48 h after stepping exercise [5]. Several studies have not found differences in muscle Ca^{2+} content [5] and Z-disks streaming [8] between women and men after eccentric–concentric exercise. Gender-related differences in muscle injury, oxidative stress, and apoptosis have been demonstrated after eccentric exercise of the knee extensor [9].

Several repeated activities with short time interval in between are sometimes performed in sports competitions and while testing of athletes. It may cause non-metabolic fatigue associated with muscle damage and delayed onset muscle soreness. This may be of particular importance if prior activities are conducted in unaccustomed conditions, e.g., unfamiliar covering of sports facilities. In such cases muscles may work in different regimens as compared to the training process. Prior heavy exercise may alter oxygen uptake (VO_2) kinetics and metabolic costs during subsequent constant exercise [10]. Data about residual effect of prior eccentric–concentric exercise on VO_2 during constant cycling exercise remains equivocal. Increased VO_2 during steady state phase of constant cycling exercise with no significant alteration on VO_2 slow component 1 h after PDJ has been reported [11]. On the contrary, no changes in VO_2 and gross cycling efficiency have been observed 48 and 72 h after prior bench stepping in women [12] or eccentric squatting exercises in men [13]. We could not find data about the residual effect of prior eccentric–concentric exercises on VO_2 during constant cycling exercise in women or data about differences of such effect between genders. The hypothesis of our study was that VO_2 changes after PDJ would be different between women and men during heavy constant cycling exercise (HCE) 45 min and 24 h after prior PDJ.

The purpose of the present study was to assess differences of the residual effect of PDJ on VO_2 during HCE and indirect muscle damage parameters between women and men.

2. Materials and methods

2.1. Subjects

A total of 11 healthy women and 8 healthy men volunteered to participate in this study after giving written informed consent. The inclusion criteria were as follows: physically activity (physical education students), age of 18–25 years, body mass index of >18.5 and <27.5 kg/m^2, no smoking, and no joint problems or other contraindications to exercise. The exclusion criteria included the following: being an athlete or participation in any formal physical exercise or sport program, chronic diseases, or any contraindications to exercise. The experimental protocol was approved by the Lithuanian Ethical Committee of Kaunas University of Medicine (No. BE-2-68) and conducted in accordance with the Declaration of Helsinki.

2.2. Peak oxygen uptake and ventilatory thresholds

The first and the second ventilatory thresholds (VT_1 and VT_2, respectively) and peak oxygen uptake (VO_2peak) were evaluated using an incremental cycling exercise test (2 W 5 s^{-1}) on an electronically braked cycle ergometer ''Ergometrics–800S'' (Ergo Line, Medical Measurement Systems; Binz, Germany) at a pedal cadence of 70 rpm. The test was started with 3 min of baseline pedaling at 20 W and continued until the intensity of cycling could not be maintained at the required level for longer than 10 s. The subjects breathed through low resistance mouthpiece and gas exchange (VO_2; pulmonary ventilation V_E; RER, respiratory exchange ratio) was measured breath-by-breath using wireless portable spirometric system ''Oxycon mobile'' (Viasys Healthcare; California, USA). Prior to each exercise session, the spirometric system was calibrated. The average value of VO_2 over the last 30 s of cycling was referred to as peak VO_2 and the VT_1 and VT_2 were determined from the result of the incremental cycling exercise. The seat and handlebar positions on the cycle ergometer were adjusted for each subject prior to initial exercise test and maintained in that position for the subsequent exercise tests. Heart rate (HR) was continuously calculated with a wireless Polar monitoring system (S810 Polar, Finland).

2.3. Heavy cycling exercise

The subjects were asked to perform HCE tests on cycle ergometer. The intensity of HCE test was Δ50% of VT_2 and VT_1 values ($[VT_1 + VT_2]/2$). The HCE was preceded by 3 min of baseline pedaling at 20 W when 6-min heavy intensity and 3-min baseline pedaling at a pedal cadence of 70 rpm were performed. Pulmonary gas exchange and HR were measured throughout HCE. This protocol was performed three times.

2.4. VO_2 kinetics analysis

VO_2 kinetics during HCE was determined using a mono- and bi-exponential model with independent time delays. The following equation was used to model mono exponential VO_2 response kinetics: $VO_2(t) = VO_2(b) + A(1 - e^{-t/\tau})$, where $VO_2(t)$ is the VO_2 at any time point; $VO_2(b)$ is the baseline VO_2 during cycling at 20 W; A is the amplitude of VO_2 response, and $(1 - e^{-t/\tau})$ is the exponential function describing the rate at which VO_2 is rising toward the amplitude. In the exponential function, t is time; τ is the time constant.

The following equation was used to model bi-exponential VO_2 response kinetics:

$$VO_2(t) = VO_2(b) + A_1(1-e^{-t/\tau_1}) + A_2(1-e^{-t/\tau_2}),$$

where $VO_2(t)$ is the VO_2 at any time point; $VO_2(b)$ is the baseline VO_2 during cycling at 20 W; A_1 and A_2 are the fast and slow component amplitudes of VO_2 response, respectively; $(1-e^{-t/\tau_1})$ and $(1-e^{-t/\tau_2})$ are the exponential functions, where t is time; τ_1 and τ_2 are the fast and slow component time constants, respectively.

The curve fitting was based on the Levenberg–Marquardt algorithm and was calculated using an iterative procedure. The best fit amplitudes of bi-exponential response were obtained by the Chi-square method. The slow component of VO_2 was also measured as the increase in VO_2 between the third minute of exercise and the end of HCE exercise (ΔVO_2, 6–3 min). The VO_2 values at 3 min were calculated as the average VO_2 for the preceding and subsequent 15 s of exercise, while the final 30 s was averaged for end-exercise VO_2 (3 min VO_2 is the VO_2 between 2 min 45 s and 3 min 15 s; and 6 min VO_2 is the VO_2 between 5 min 30 s and 6 min exactly).

Oxygen uptake of heart and respiratory muscles contributes to VO_2, and changes in V_E, and HR could have a significant impact on VO_2 response to repetitive exercise. An attempt was made to evaluate the importance of these factors to VO_2. The oxygen costs of cardiac work were assumed to be 0.2 ml/beat, while VO_2 of respiratory muscles was calculated as previously described [14]. For this particular correction, work of breathing was calculated at first:

$$W_B = -0.251 + 0.0382 \cdot V_E + 0.00176 \cdot V_E^2,$$

where W_B is work of breathing, and V_E is expiratory pulmonary ventilation. Then VO_2 of respiratory muscles was estimated as:

$$V_{RM}O_2 = 34.9 + 7.45 \cdot W_B,$$

where $V_{RM}O_2$ is O_2 uptake of the respiratory muscles, W_B is work of breathing:

$$cVO_2 = VO_2 - V_{RM}O_2,$$

where cVO_2 is corrected VO_2, $V_{RM}O_2$ is O_2 uptake of the respiratory muscles, VO_2 is the whole body oxygen uptake. The relative VO_2 was calculated as percentage alteration (increase/decrease) under fatigue conditions (45′ PDJ; 24 h PDJ) compared with CON as a datum-level.

2.5. Prior drop jumps exercise

Subjects performed 100 drop jumps from a 0.47 m stage with 20 s of recovery between each drop jump. After the drop the subject got to amortization phase while the knee joints were flexed at the angle of 90° and immediately jump up as high as possible (with hands on hips).

2.6. Plasma creatine kinase activity and blood lactate

Blood sample (25 μL) for the measurement of blood lactate (La) concentration (Accutrend Portable Lactate Analyzer, Roche, Germany) was taken from fingertips. Approximately 2500 μL of capillary blood sample was collected into a tube containing lithium heparin to determine the CK (IU/L) activity by using an automatic biochemical analyzer Spotchem EZ SP-4430 (Arkray Inc, Kyoto, Japan).

2.7. Muscle soreness and perceived exertion rating

DOMS was reported subjectively performing one squat using a visual scale of 0–10 points in which 0 represented no pain and 10 represented intolerably intense pain. The subject was asked to rate their perceived exertion (RPE) using the Borg scale, ranging from 6 to 20 (6, nothing at all; 20, maximal exertion).

2.8. Experimental protocol

Subjects reported to the laboratory on four separated days within a 2–3-week period. Exercise testing was performed at approximately the same time of day for each subject. The first session was used to familiarize subjects with the testing equipment and procedure. In the same session, each subject performed an incremental cycling exercise test (after 5-min warm-up and 5-min rest). Subsequently, on three separate occasions, the subjects performed one control (CON) HCE and two HCE under fatigue conditions (45 min after PDJ [45′ PDJ]; 24 h after PDJ [24 h PDJ]). The first HCE under fatigue conditions was CON performed 45 min after PDJ (after 5-min of not-intensive warming-up on a cycle ergometer (40 W at a pedal cadence of 70 rpm) and 5 practice drop jumps) (45′ PDJ) at least after 2 days and the second 24 h after drop jumps (24 h PDJ). The La concentration was taken at 5 min and 20 min after ICE test and at the end of 6th minute of HCE tests. At the end of 6th minute of HCE, the subjects were asked to rate their perceived exertion. CK activity was measured and DOMS was rated 24 h after PDJ.

2.9. Statistical analysis

Cardiorespiratory parameters and RPE were analyzed using two-way repeated measures ANOVA design evaluating time and gender as the main effects. CK, DOMS, and anthropometric parameters were analyzed using an independent one-way ANOVA (gender) and paired one-way ANOVA (CON; 45′ PDJ; 24 h PDJ). Significant results were further analyzed using Turkey HDS post hoc test. Statistical significance was accepted when $P < 0.05$. All data are reported as the mean (SD).

3. Results

The physical characteristics and aerobic capacity values of incremental cycling exercise are presented in Table 1. The relative mean work rate of HCE was similar ($P = 0.24$) in both groups (65.4% [5.1%] and 63.8% [3.9%] of maximal power in women and men, respectively).

The La concentration did not increase both in women (CON, 6.71 [2.01]; 45′ PDJ, 6.96 [2.21]; 24 h PDJ, 7.05 [2.33]) and in men (CON, 6.10 [1.09]; 45′ PDJ, 6.26 [1.34]; 24 h PDJ, 6.16 [1.01]) under fatigue conditions compared with CON. RPE was rated as heavy in both women (CON, 14.8 [1.4]; 45′ PDJ, 15.7 [1.9]; 24 h PDJ, 15.7 [2.2]) and men (CON, 14.8 [0.5]; 45′ PDJ, 15.1 [1.4]; 24 h PDJ, 15.0 [1.4]) under different testing conditions. There was no gender difference in RPE and La concentration.

Women and men felt moderate DOMS (a score of 5.1 [2.6] in women and 4.8 [2.0] in men) on a 10-point scale 24 h after PDJ. The serum CK activity was significantly higher in men (600.4 [350.2] IU/l) compared with women (306.2 [281.2] IU/l) 24 h after DJ ($P \leq 0.05$). We estimated the significant positive correlation between DOMS and CK in women ($r = 0.83$) and in men ($r = 0.93$).

V_E, RER and HR during last three min of cycling did not differ between testing conditions as well as between groups except for HR which was higher in the female group (Table 2).

The cVO_2 during 3–6 min of HCE did not differ between CON and fatigue conditions (45′ PDJ; 24 h PDJ) in women (Fig. 1) but this indicator significantly increased by ~6–9% 45′ PDJ compared with CON in men ($P \leq 0.01$) (Fig. 2).

The τ_1 of VO_2 primary component decreased 24 h PDJ compared with CON in men ($P \leq 0.04$). The τ_2 of slow component decreased 45′ PDJ compared with CON ($P \leq 0.05$) but it was faster 24 h PDJ compared with 45′ PDJ ($P \leq 0.05$) in men. The τ_m of VO_2 kinetics which was calculated using mono-exponential model decreased 45′ PDJ and 24 h PDJ compared with CON in men group ($P \leq 0.03$). VO_2 (b), ΔVO_2 (6–3 min), $A_1 + A_2$, VO_2end-ex; and A_m did not differ under different testing conditions and between groups (Table 3). A significant positive correlation between an increase of cVO_2 45′ PDJ (Fig. 3) and 24 h PDJ (Fig. 4) and plasma CK activity 24 h after PDJ was observed in the male but not in the female group.

Table 1 – Subjects' descriptive characteristics.

	Women ($n = 11$)	Men ($n = 8$)
Age, years	21.5 (1.9)	20.8 (1.9)*
Weight, kg	60.8 (4.5)	78.4 (10.4)*
Height, m	1.70 (0.06)	1.82 (0.05)*
Free fat mass, kg	44.9 (2.3)	66.0 (7.2)*
Fat mass, %	25.9 (3.8)	15.4 (3.3)*
VT_1, W	104.3 (20.0)	126.8 (26.7)
VT_2, W	153.3 (21.6)	240.0 (47.3)*
Maximal power, W	198.0 (20.0)	293.8 (65.2)*
VO_2peak, l min^{-1}	2.213 (0.353)	3.545 (0.728)*
VO_2peak, ml kg^{-1} min^{-1}	36.37 (5.01)	45.02 (5.17)*
VO_2FFMpeak, ml kg^{-1} min^{-1}	49.3 (7.2)	53.3 (6.5)
HRmax, 1 min^{-1}	187.5 (8.9)	188.2 (8.2)

The first ventilatory threshold (VT_1), the second ventilatory threshold (VT_2), oxygen uptake (VO_2peak) and maximal heart rate (HRmax) over the last 30 s during incremental cycling exercise. Values are means (SD).
* Statistically significant differences between men and women, $P < 0.05$.

4. Discussion

The original finding of this investigation was the different influence of PDJ on VO_2 response during heavy cycling between men and women. 45 min after PDJ the significant increase in VO_2 during steady state of HCE was observed only in men and the relative magnitude of VO_2 changes was positively correlated with blood CK activity 24 h after PDJ in the male group.

The investigation by Ratkevicius and colleagues [11] also demonstrated overall VO_2 increase during three different

Table 2 – Pulmonary ventilation (V_E), respiratory exchange ratio (RER) and heart rate (HR) during the last three minutes of heavy cycling exercise under control (CON) and fatigue conditions (45 min after drop jumps (45′ PDJ), 24 h after drop jumps (24 h PDJ)).

	Women ($n = 11$)			Men ($n = 8$)		
	CON	45′ PDJ	24 h PDJ	CON	45′ PDJ	24 h PDJ
V_E, l min^{-1}	61.08 (13.42)	63.26 (12.28)	60.52 (13.37)	61.69 (15.55)	67.59 (17.13)	66.92 (16.60)
RER	1.064 (0.073)	1.073 (0.099)	1.055 (0.078)	1.028 (0.036)	1.029 (0.056)	1.026 (0.022)
HR, beats min^{-1}	174.5 (8.1)	175.7 (9.0)	171.6 (9.6)	156.0 (7.8)*	161.6 (11.9)*	155.6 (8.4)*

Values are means (SD).
* Statistically significant differences between men and women, $P < 0.05$.

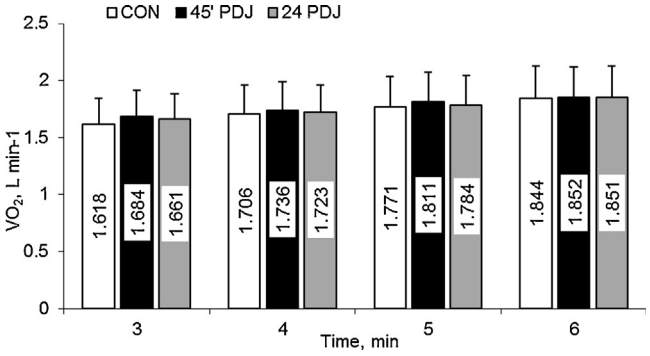


Fig. 1 – Mean response of corrected oxygen uptake (VO_2) during heavy constant cycling exercise under control condition (CON) in women's group; 45 min after prior drop jumps (45′ PDJ) and 24 h after prior drop jumps (24 h PDJ). Values are group means with standard deviation (SD) indicated by the bars.

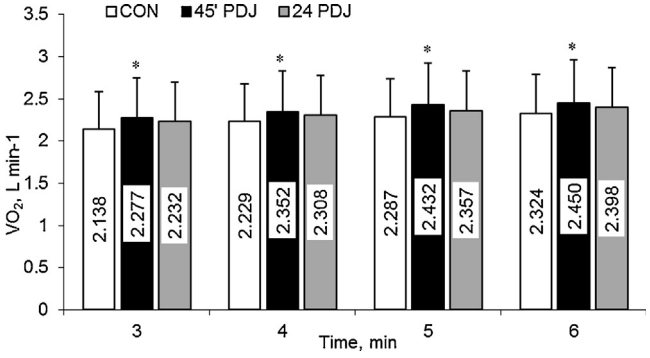


Fig. 2 – Mean response of corrected oxygen uptake (VO_2) during heavy constant cycling exercise under control condition (CON) in men's group; 45 min after prior drop jumps (45′ PDJ) and 24 h after prior drop jumps (24 h PDJ). Values are group means with standard deviations (SD) indicated by the bars. * Statistically significant difference between CON and 45′ PDJ, $P \leq 0.01$.

workloads (105, 140, and 175 W) with no alteration on the slow component of VO_2 kinetics comparing control and fatigue (1 h after 100 drop jumps) conditions and it was similar to the present study results where by ~7–9% increased VO_2 during plateau of heavy (183.4 [34.8] W) cycling performed 45 min after PDJ compared with CON in men was observed. Additionally, in the present study, VO_2 did not differ 24 h after PDJ compared with CON in men and in women and these findings are coincident with other studies that did not demonstrate changes in VO_2 during heavy cycling performed 24–48 h after eccentric exercise [15] in men and after 48–72 h in women [12]. The kinetics of VO_2 did not change in the study by Schneider et al. [12] as well, but they measured VO_2 during heavy cycling 48 h after stepping exercise. In our study, VO_2 kinetics also did not change 24 h after PDJ in the female group, but it was faster both at 45 min and 24 h after PDJ in the male group. This was an unexpected finding because most studies showed no change of VO_2 kinetics or even slowing of that after prior eccentric concentric exercise [16]. It was found that VO_2 kinetics was influenced by muscle fiber type and motor unit recruitment [17]. It is supposed that prior eccentric exercise could impair both convective and diffusive muscle oxygen supply mainly in type II fibers [16]. The faster VO_2 kinetics in our study during recovery after PDJ may be explained by at least two reasons. First of all it is known that prior heavy exercise can accelerate VO_2 kinetics during subsequent heavy exercise [18]. Thus, some residual effects of PDJ could influence VO_2 response in our study at least at 45 min of recovery. On the other hand, greater damage of type II fibers usually found after such kind of prior exercise could lead to more reliance on type I fibers activity during subsequent HCE in our study. Indeed, Davies et al. [13] verified reduction in the amplitude of the VO_2 slow component suggesting an altered motor unit recruitment pattern (i.e., increased recruitment of slow-twitch motor units) consequent to muscle damage.

The PDJ did not have significant effect on RPE, La concentration and V_E in the present study. On the contrary, enhanced RPE, V_E [16] and La concentration [12] were observed after eccentric exercise.

Plasma CK activity increased to 306.2 (281.2) IU/l in women and to 600.4 (350.2) IU/l in men 24 h after PDJ and this value exceeds damage threshold [19]. The CK differences between men and women in our study are in agreement with a recent study where gender differences in CK expression following acute resistant strenuous exercise were demonstrated [20]. The plasma CK elevation probably is linked to an inflammatory response [8,21]. Despite the similarly increased plasma CK activity and the same amount of Z-disk damage after eccentric exercise in men and women, women showed less inflammation supposedly because of the mediating role of estradiol [22] and this presumption confirms a resent investigation on men suggesting that 17β-estradiol supplementation attenuates neutrophil infiltration [23].

In the present study, women and men felt moderate DOMS (a score of 5.1 [2.6] and 4.8 [2.0], respectively) on a 10-point scale. DOMS was lower of upper limbs in women [24] and in contrast women felt significant higher DOMS of lower limbs compared with men after eccentric exercises [5]. The gender difference in DOMS depends upon the methodology and measuring sensation. Moreover, the use of DOMS only is a poor reflector of eccentric exercise-induced muscle damage indicator because of generally poor correlations between DOMS and other indicators [25]. On the contrary, we found significant correlation between CK and DOMS in women ($r = 0.83$) and men ($r = 0.93$) 24 h after PDJ. Despite changes in force generating capacity of thigh muscles which were not measured in our study, our experiment was performed like in the previous studies where maximal voluntary contraction force was decreased by ~30% as measured 20 min after the exercise and still showed ~15% deficit 24 h after the exercise [26] in men. Other studies have shown no significant gender differences in force loss and recovery of upper limbs between men and women after eccentric exercise [6,7] or larger strength loss in women than the men 1–3 days after eccentric step exercise [5]. However, the investigations of correlations between functional and biochemical outcomes of eccentric exercise suggest that CK increases associate with MVC decreases because of statistically significant negative correlation ($r = -0.7$) between these parameters 24–48 h after stretch

Table 3 – Oxygen uptake kinetics parameters during heavy cycling exercise under control (CON) and fatigue conditions (45 min after drop jumps (45′ PDJ), 24 h after drop jumps (24 h PDJ)).

	Women			Men		
	CON	45′ PDJ	24 h PDJ	CON	45′ PDJ	24 h PDJ
VO_2 rest	0.319 (0.071)	0.312 (0.056)	0.309 (0.060)	0.444 (0.093)*	0.432 (0.093)*	0.435 (0.079)*
$VO_2(b)$	0.722 (0.106)	0.695 (0.061)	0.697 (0.052)	0.881 (0.094)*	0.887 (0.080)*	0.879 (0.113)*
A_1, l min^{-1}	0.783 (0.216)	0.853 (0.207)	0.926 (0.176)	1.046 (0.278)*	1.033 (0.420)*	0.962 (0.294)*
τ_1, s	12.9 (5.7)	12.9 (5.7)	15.6 (5.0)	19.21 (8.10)	15.37 (6.30)	11.4 (4.2) #
A_2, l min^{-1}	0.682 (0.150)	0.551 (0.186)	0.487 (0.170) #	0.892 (0.256)*	0.889 (0.251)*	0.884 (0.242)
τ_2, s	228.8 (91.5)	218.6 (124.1)	245.6 (117.6)	288.1 (205.5)	146.2 (109.9) $,*	142.3 (73.5) #,*
$A_1 + A_2$	1.465 (0.231)	1.404 (0.276)	1.413 (0.264)	1.830 (0.481)*	1.837 (0.495)*	1.846 (0.388)*
$\Delta VO_{2(6–3\ min)}$	0.206 (0.107)	0.173 (0.089)	0.197 (0.117)	0.180 (0.065)	0.191 (0.056)	0.179 (0.054)
VO_2 end ex	2.054 (0.221)	2.003 (0.256)	1.998 (0.275)	2.503 (0.491)*	2.630 (0.552)*	2.651 (0.483)*
A_m	1.186 (0.243)	1.228 (0.252)	1.211 (0.220)	1.600 (0.457)*	1.711 (0.466) *,$	1.684 (0.447)*
τ_m	47.63 (17.72)	39.73 (15.14)	38.85 (10.92)	46.01 (10.07)	39.59 (7.92)$	40.66 (7.77)

Oxygen uptake (VO_2) baseline ($VO_2(b)$); VO_2 kinetics primary and slow components amplitudes (A_1 and A_2), respectively; VO_2 kinetics primary and slow components time constants (τ_1 and τ_2) respectively; VO_2 kinetics slow component ($\Delta VO_{2(6–3\ min)}$); end exercise VO_2 (VO_2 end ex). Values are means (SD).

Statistically significant differences between CON and 24 h PDJ; $P < 0.05$.

$ Statistically significant differences between CON and 45′ PDJ; $P < 0.05$.

† Statistically significant differences between 45′ PDJ and24 h PDJ; $P < 0.05$.

* Statistically significant differences between women and men; $P < 0.05$.

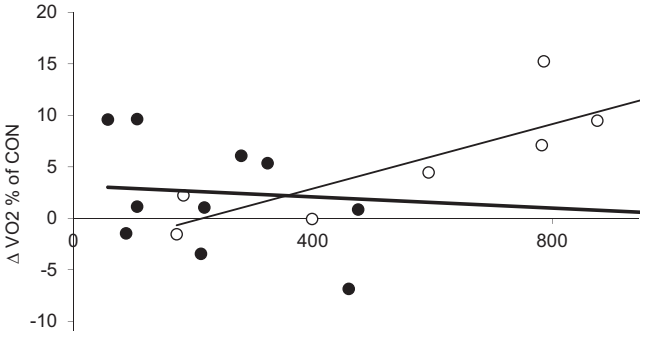


Fig. 3 – The correlation between changes in oxygen uptake (VO_2) (% from control heavy cycling conditions (CON)) during constant heavy cycling 45 min after prior drop jumps and plasma creatine kinase (CK) activity 24 h after prior drop jumps in men (○) and women (●).

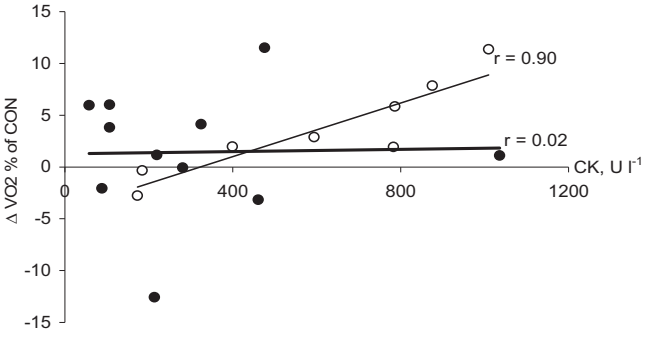


Fig. 4 – The correlation between changes in oxygen uptake (VO_2) (% from control heavy cycling conditions (CON)) during constant heavy cycling 24 h after prior drop jumps and plasma creatine kinase (CK) activity 24 h after prior drop jumps in men (○) and women (●).

shortening leg exercise [27] and 1–4 days after ($r = -0.75$ to -0.59) elbow flexors eccentric exercises which were found [28]. In the present study, it is possible to suppose that MVC of thigh muscle decreased more in men than in women 24 h after PDJ because of higher plasma CK activity in men. The positive correlation between CK and relative change of VO_2 in men coincides with the data that delayed recovery of the muscle force response is related to changes in CK [29].

Thus the VO_2 increases at 45 min after PDJ and alteration of VO_2 kinetics slow component could be explained by muscle damage after repetitive drop jumps that could produce different patterns of muscle fiber recruitment [11]. An elevated resting metabolic rate after the muscle-damaging exercise [30] can also influence VO_2 during submaximal cycling. It was suggested that the elevated rate of protein breakdown and resynthesis after muscle-damaging exercise

might cause increase in VO_2 during constant intensity exercise [30].

A statistical limitation of the current study might be the rather small samples of participants. This limits the generalizability of this study. The medium effect size (0.25–0.30) was observed for the VO_2 changes after prior exercise in the male group though the changes were significant at alpha level of $P = 0.01$. Thus, for a significance level of 0.05, with a medium effect size of 0.25, to achieve a power of 0.80, a total sample size of 80 subjects in each group would be required. This is usually impossible in such type of biomedical studies. So the additional research with using more powerful muscle damaging protocols is needed for confirmation of differences between genders.

5. Conclusions

In summary, prior eccentric–concentric exercise of thigh muscles (100 drop jumps) accelerates VO_2 kinetics at the start and increases VO_2 during steady state of heavy cycling only in the male group. So, prior exercise of such type has a higher negative impact on cycling economy in men than in women and this might be related to greater muscle damage and fatigue in physically active male persons after plyometric exercise.

Conflict of interest

The authors state no conflict of interest

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