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The Effects of Muscle Damage on Running Economy in Healthy Males

Abstract

Published information on aspects related to muscle damage and running economy is both limited and contradictory. To contribute to the current debate, we investigated the effects of an eccentric exercise session on selected muscle damage indices in relation to running economy using 10 (mean age 23 ± 1 years) healthy male volunteers. The eccentric exercise session consisted of 120 (12×10) maximal voluntary repetitions by each randomly selected leg at the angular velocity of $1.05 \text{ rad} \cdot \text{s}^{-1}$. Muscle damage (creatine kinase, delayed onset muscle soreness, range of movement, and eccentric, concentric and isometric [at 60° and 110° knee flexion] peak torque) and running economy (oxygen consumption, pulmonary ventilation, respiratory exchange ratio

and breaths per minute during treadmill running at 133 and $200 \text{ m} \cdot \text{min}^{-1}$) indicators, were assessed pre-, 24-, 48-, 72- as well as 96-h after exercise. All muscle damage indicators revealed significant changes at almost all time-points of assessment compared to pre-exercise data ($p < 0.05$). However, none of the running economy parameters disclosed any significant change throughout the study ($p > 0.05$). It was concluded that changes in muscle damage and muscle performance as measured in this study are not reflected by concomitant alterations in running economy at submaximal intensities.

Key words

Oxygen consumption · delayed onset muscle soreness · range of movement · isokinetic peak torque

Introduction

Resistance training-programmes, particularly the eccentrically performed action of downhill running, have been used by endurance athletes in order to enhance muscle performance [5,14,38]. However, resistance eccentric exercise and downhill running, especially when they are unaccustomed activities for the athletes, may cause delayed onset muscle soreness (DOMS), large increases in the activity of muscle specific enzymes, and reduction in muscular performance of the affected muscles [8,9]. These symptoms typically begin 12–24 h after unaccustomed exercise, peak after 24–72 h and then subside to pre-exercise levels three to seven days after the initial exercise [2].

Most of the published information regarding muscle performance, in relation to muscle damage, has been based on isometric dynamometry [30,36,37]. However, daily human movements involve eccentric, as well as concentric and isometric muscle-actions, which normally demonstrate different physiological characteristics. Isometric contractions are mainly characterised by elevated intramuscular pressure or increasing activity of metabolites associated with fatigue [41] while the elastic component and efferent neural activation are the main physiological attributes of eccentric [22] and concentric actions [21] respectively. Therefore, it would be more appropriate to consider all three types of contraction when assessing changes in muscle performance.

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Maximum oxygen uptake ($\dot{V}O_{2\max}$) is an essential factor for success in endurance running events [12,17,34]. However, running economy, which is defined as oxygen consumption at a constant submaximal velocity ($\dot{V}O_2$) [13] can significantly affect the competition result between athletes with the same $\dot{V}O_{2\max}$ [11,13,29]. There has been little research investigating the effects of muscle damage on running economy.

To our knowledge, there are only three sets of data on DOMS in relation to running economy. The first revealed that lower extremity resistance exercise and the resultant DOMS did not affect $\dot{V}O_2$ levels during submaximal treadmill running [39]. This is in line with an earlier study whereby downhill running did not affect $\dot{V}O_2$ levels, even if small but significant alterations in lower body kinematics involving hip, knees and ankles were identified [18]. However, these studies contradict the third available investigation which demonstrated that DOMS can significantly alter running economy indicators [6]. Given the dearth and contradictory nature of the existing data, the purpose of the present study was to further investigate the effects of a single eccentric exercise bout, with controlled isokinetic contractions, on running economy and related physiologic measures.

Methods

Subjects

Ten healthy males (age 23 [\pm 1] years, height 175 [\pm 0.5] cm and mass 74 [\pm 0.5] kg) volunteered. Subjects had no experience of regular eccentric exercise training for at least six months prior to the study and they were not taking anti-inflammatory drugs. They were also instructed to abstain from strenuous exercise activities three days prior to and during data collection. Subjects read and signed an informed consent form according to the standards of the Thessaly University Ethics Committee.

Procedures

Subjects visited the data collection venue at nine different occasions. The first and second were reserved for familiarisation purposes. $\dot{V}O_{2\max}$ and baseline data were collected during the third and fourth visits respectively. The fifth visit was used for eccentric exercise purposes while the remaining visits were reserved for the follow-up measurements 24-, 48-, 72- and 96-h after the eccentric exercise, in line with previously adopted protocol [32].

$\dot{V}O_{2\max}$ for all subjects was evaluated during treadmill (Powerjog, GXC200, UK) running about a week before the start of data collection, using an automated gas analyser (Sensormedics, V_{\max} 29, Yorba Linda, California, USA) and a previously used protocol [24]. The gas analyser was calibrated using 26% oxygen (O_2) and 4% dioxide carbon (CO_2) according to the instructions provided by the manufacturer. The protocol consisted of an initial run at 167 $m \cdot \min^{-1}$, which was continuously increased by 17 $m \cdot \min^{-1}$ every two minutes, at 0% inclination, until subjects reached a state of volitional fatigue. $\dot{V}O_{2\max}$ ($ml \cdot kg^{-1} \cdot \min^{-1}$) was achieved if one of the following criteria was met: a) heart rate (HR) within one standard deviation of age-based predicted maximal value, and b) respiratory exchange ratio (RER) greater than 1.08.

Volunteers underwent two isokinetic exercise sessions, one on each leg selected in a random order. For each exercise session subjects had to accomplish 12 sets of 10 eccentric maximal voluntary contractions (MVC) in seated (90° hip angle) position. This form of exercise was used as it is more closely related to exercise induced muscle damage than either isometric or concentric exercise [3,16,33]. A two-minute rest interval was placed between sets. Prior to each exercise session, subjects performed a warm-up consisting of eight-min cycling on a Monark cycle ergometer (Vansbro, Sweden) at 70 rpm and 50 W, followed by five-min of stretching exercises.

Muscle damage torque and range of motion (ROM) indicators were assessed using an isokinetic dynamometer (Cybex Norm Lumex, Ronkonkoma, NY, USA), previously used in similar studies [31,33]. The dynamometer was calibrated weekly according to the instructions provided by the manufacturer, while the details of the assessment protocol appear elsewhere [23]. Subjects were coupled to the dynamometer by aligning the lateral femoral condyle with the axis of rotation of the dynamometer and attaching the ankle cuff proximal to the lateral malleolus. Each subject's functional range of motion was set electronically between 0° and 120° of knee flexion to prevent hyperextension and hyperflexion. Gravitational corrections were made for the effect of limb weight on torque measurements. All eccentric and concentric activities were conducted at the angular velocity of 1.05 $rad \cdot s^{-1}$. Feedback on the eccentric exercise intensity and duration was automatically provided by the isokinetic dynamometer.

Muscle damage indicators

- 1. Creatine kinase (CK).** Blood samples were drawn from an antecubital vein into plain evacuated test tubes at both sessions. The blood was allowed to clot at room temperature for 30 min and centrifuged at 1500 $\cdot g$ for 10 min. The serum layer was removed and frozen at $-20^\circ C$ until analyzed. CK was determined spectrophotometrically (Milton Roy, Spectronic 401, USA) in duplicate using a commercial available kit (Megalab, Athens, Greece). The normal reference range of CK activity for men using this method is 45 – 130 IU.
- 2. DOMS.** Each subject determined soreness by palpation of the muscle belly and the distal region of the vastus medialis, vastus lateralis and rectus femoris in a seated position with the muscles relaxed. Perceived soreness was then rated on a scale ranging from 1 (normal) to 10 (very, very sore). This scale has been previously documented by other investigators [10,19].
- 3. Range of motion (ROM).** The subjects lied prone on the previously described isokinetic dynamometer and their knee joint was attached to the lever arm by aligning the lateral femoral condyle with the axis of rotation of the dynamometer and attaching the ankle cuff proximal to the lateral malleolus. The position of the chair and the lever arm were recorded and were checked each time. From the full-extended position, a passive flexion was performed by one of the investigators at a very low angular velocity (0.35 $rad \cdot s^{-1}$) and the position where the subject felt any discomfort was taken to indicate the pain-free ROM.
- 4. Muscle performance.** The same isokinetic dynamometer (Cybex Norm) was used for the evaluation of muscle performance

of the knee extensors (i.e., eccentric peak torque [EPT], concentric peak torque [CPT] and isometric peak torque at 60° [IPT₆₀] and 110° [IPT₁₁₀] knee flexion). The best of three MVC was recorded for EPT, CPT, IPT₆₀ and IPT₁₁₀. There was three minutes rest between contraction modes (eccentric, concentric and isometric) whereas the order of contraction modes was randomised between subjects.

Running economy indicators

Running economy was assessed from measurement of $\dot{V}O_2$, pulmonary ventilation (\dot{V}_E), RER, number of breaths per minute (BPM), and HR (Polar S610™, Electro Oy, Finland) during submaximal treadmill running. The submaximal test consisted of two randomly selected velocities at 133 and 200 m·min⁻¹ as previously suggested [7,26]. Each test lasted six minutes with five minutes rest between tests. Running economy indicators were obtained by averaging six consecutive 20-s collection periods during the last two minutes of each running speed.

Since it is known that temperature can affect running economy [27,35], temperature conditions in the laboratory were stable during the experiment ($23 \pm 1^\circ\text{C}$). Additionally, volunteers used the same shoes for each running speed [29].

Data analysis

The Kolmogorov-Smirnov test of normality revealed that none of the variables studied required logarithmic transformation. However, due to lack of homogeneity in variance, non-parametric analyses were applied for CK and DOMS as previously suggested [40]. 1×5 (exercise \times time) repeated measures ANOVA and pairwise comparisons through simple main effect analysis were used to analyse all measured parameters, except CK, and DOMS. T-tests were used in order to find any differences between the right and left quadriceps in DOMS, ROM and all muscle performance indicators. The significance level was set at $p < 0.05$.

Results

Mean $\dot{V}O_{2\max}$ and HR were $52.5 (\pm 2.4) \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $197.5 (\pm 5.5) \text{ beats}\cdot\text{min}^{-1}$, respectively. The work production and the exercise intensity during the eccentric exercise was not significantly different ($p > 0.05$) between the two lower extremities for all subjects revealing an average value of $27\,160 (\pm 928) \text{ J}$ and $83.4 (\pm 3.8) \%$ of their eccentric peak torque, respectively. There was no significant difference ($p > 0.05$) between the left and right quadriceps regarding DOMS, ROM and muscle performance. Therefore, all further references to these parameters will be the mean of the two values.

Muscle damage indicators

Compared with baseline data, serum CK (Fig. 1), DOMS (Fig. 2), and ROM (Fig. 3) were altered significantly ($p < 0.05$) at all post eccentric time-points. Also compared with baseline data, EPT (Fig. 4) and IPT₁₁₀ (Fig. 5) declined significantly ($p < 0.05$) at all time-points of post exercise assessment while CPT (Fig. 4) and IPT₆₀ (Fig. 5) declined significantly ($p < 0.05$) only until 72 and 48 h, respectively.

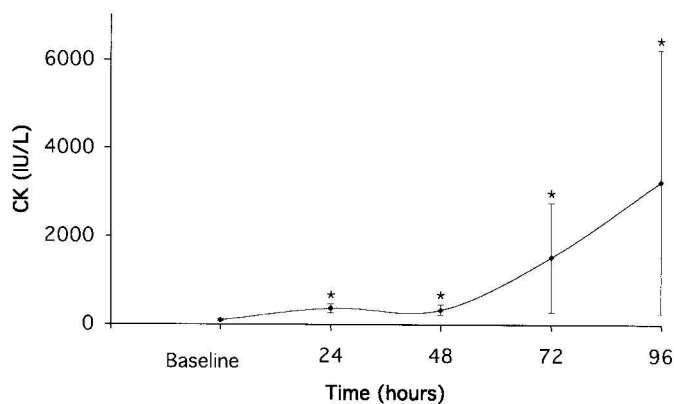


Fig. 1 Creatine kinase (CK) activity in blood serum pre-, 24-, 48-, 72- and 96-h after eccentric exercise. Data are reported as mean \pm SEM. * $p < 0.05$ significant difference compared to baseline values.

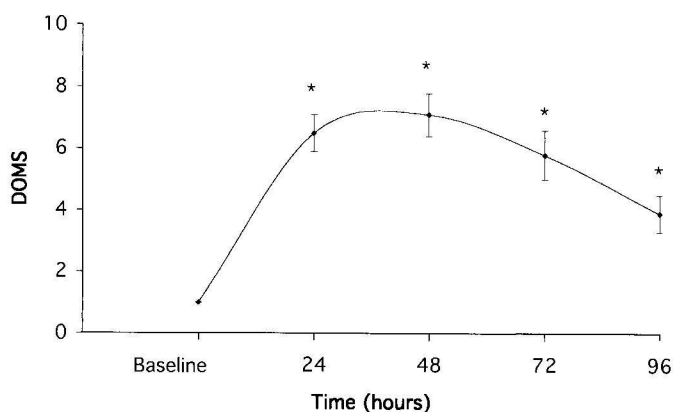


Fig. 2 Delayed onset muscle soreness (DOMS), pre-, 24-, 48-, 72- and 96-h after eccentric exercise. Data are reported as mean \pm SEM. * $p < 0.05$ significant difference compared to baseline values.

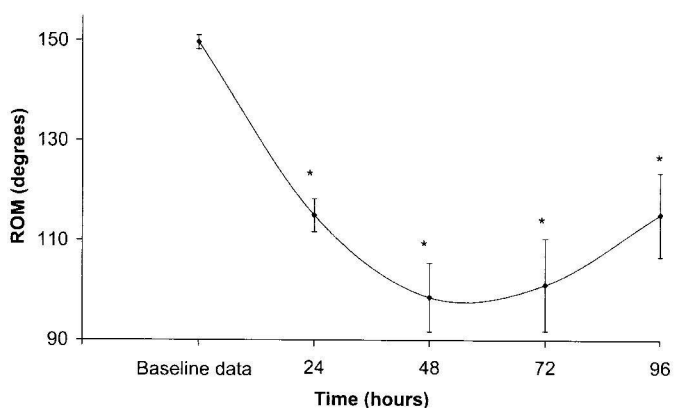


Fig. 3 Range of movement (ROM), pre-, 24-, 48-, 72- and 96-h after eccentric exercise. Data are reported as mean \pm SEM. * $p < 0.05$ significant difference compared to baseline values.

Running economy indicators

The intensity used to evaluate running economy was on average 55% and 75% of $\dot{V}O_{2\max}$ for the 133 and 200 m·min⁻¹ velocities, respectively. The running economy indicators were not significantly ($p > 0.05$) changed at any time-point of assessment (Table 1).

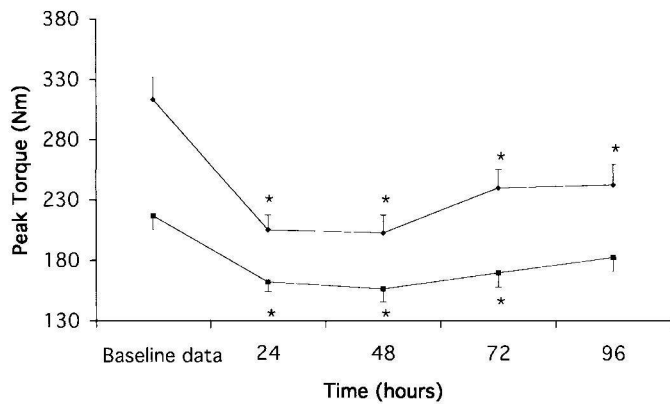


Fig. 4 Eccentric (♦) and concentric (■) peak torque, pre-, 24-, 48-, 72- and 96-h after eccentric exercise. Data are reported as mean ± SEM. * p < 0.05 significant difference compared to baseline values.

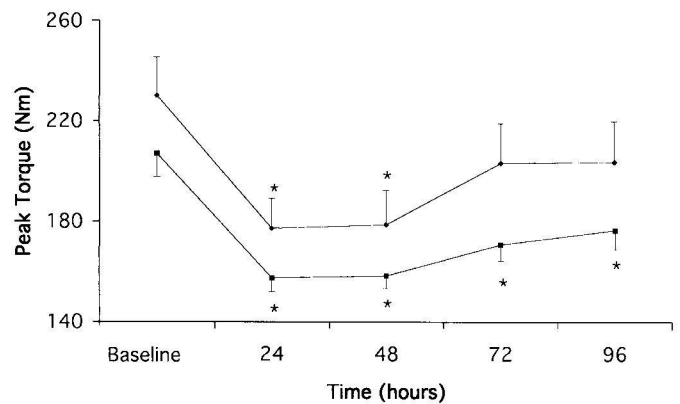


Fig. 5 Isometric peak torque at 60° knee flexion (♦) and at 110° knee flexion (■), pre-, 24-, 48-, 72- and 96-h after eccentric exercise. Data are reported as mean ± SEM. * p < 0.05 significant difference compared to baseline values.

Table 1 Running economy indicators at the time points of assessment after eccentric exercise. Data are reported as mean ± SEM

Indicators	Baseline values (n = 10)	24 hours (n = 10)	48 hours (n = 10)	72 hours (n = 10)	96 hours (n = 10)
$\dot{V}O_2 - 133 \text{ m} \cdot \text{min}^{-1}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)#	27.9 ± 0.8	28.6 ± 1.3	28.3 ± 1.2	27.4 ± 1	27.1 ± 1
$\dot{V}O_2 - 200 \text{ m} \cdot \text{min}^{-1}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	37.8 ± 0.6	39.2 ± 1.2	39.3 ± 1.4	38.8 ± 1	38.4 ± 1.2
$\dot{V}_E - 133 \text{ m} \cdot \text{min}^{-1}$ ($\text{l} \cdot \text{min}^{-1}$)#	50.0 ± 1.5	53.4 ± 2.3	54.9 ± 3.0	54.9 ± 2.5	55.6 ± 2.9
$\dot{V}_E - 200 \text{ m} \cdot \text{min}^{-1}$ ($\text{l} \cdot \text{min}^{-1}$)	75.0 ± 2.6	81.1 ± 4.9	79.7 ± 4.6	77.1 ± 4.7	78.1 ± 5.1
RER - 133 m · min ⁻¹ #	0.909 ± 0.02	0.905 ± 0.02	0.923 ± 0.02	0.929 ± 0.02	0.915 ± 0.02
RER - 200 m · min ⁻¹	0.956 ± 0.02	0.973 ± 0.02	0.966 ± 0.02	0.956 ± 0.02	0.962 ± 0.01
BPM - 133 m · min ⁻¹ (No · min ⁻¹)#	27.0 ± 2.7	30.8 ± 2.8	35.2 ± 2.6	34.1 ± 3.0	35.2 ± 2.9
BPM - 200 m · min ⁻¹ (No · min ⁻¹)	38.5 ± 2.9	39.7 ± 2.6	40.1 ± 3.2	40.8 ± 3.3	41.9 ± 3.2
HR - 133 m · min ⁻¹ (beats · min ⁻¹)#	138.8 ± 6	142.2 ± 10.7	138.0 ± 8.0	135.4 ± 9.2	136.0 ± 9.1
HR - 200 m · min ⁻¹ (beats · min ⁻¹)	166.4 ± 6.6	166.6 ± 6.5	165.8 ± 6.3	164.2 ± 6.1	161.0 ± 7.9

Indicates significant difference between the two running speeds (p < 0.05) at all post exercise time-points. $\dot{V}O_2$: oxygen consumption, \dot{V}_E : pulmonary ventilation, RER: respiratory exchange ratio, BPM: number of breaths per minute, HR: heart rate

Discussion

The purpose of the present study was to investigate the effects of a single eccentric exercise bout, with controlled isokinetic contractions, on running economy. All muscle damage and muscle performance indicators revealed significant changes compared to baseline data at almost all time-points of post exercise assessments. However, none of the running economy indicators were significantly affected.

These findings are in line with a published report [18], in which 30 min of downhill running did not alter running economy. In contrast, the present data disagree with the findings of a recent study [6], in which 30 min of downhill running did affect subjects' running economy. The fact that in the former study, as well as in the current one, recreational athletes were used compared to trained runners utilised by the latter investigation may account for the observed discrepancy. It seems, therefore, that running economy may be less sensitive in recreational athletes as gait patterns may not be as well refined as in trained runners. It

could also be suggested that the exercise performed after the initial eccentric session, which was found to provide some relief from DOMS [1], contributed to the lack of significant changes on running economy parameters.

The present results are also in line with a previously published set of data [39] which revealed that DOMS caused by a series of lower extremity submaximal resistance exercise did not affect $\dot{V}O_2$ during 30 min of submaximal running. However, this type of resistance exercise provides insufficient control of intensity, duration and rest between sets.

The fact that running economy data were not affected by muscle damage may be due to running velocities themselves. Indeed, it has been suggested that the intensity of running tests influences running economy [28]. Submaximal muscular activity depends mostly on type I fibres whereas the maximal equivalent on type II fibres [25]. Previous studies have shown that type II may be more susceptible to injury from maximal eccentric exercise, compared to type I fibres [4,20]. It could be argued, therefore,

that type I muscle fibres may have not been as affected during the current eccentric exercise thus maintaining normal recruitment patterns and metabolic function during the submaximal running used for the evaluation of running economy.

The lack of significant changes in running economy following the isokinetic resistance exercise may also be due to different muscle recruitment patterns adopted by the two exercise modes. The current eccentric knee flexion exercise resulted in damage mainly to quadriceps muscles. However, this damage was perhaps "masked" by the fact that, during running, a significantly greater number of lower limb musculature [15] are used, which – apart from quadriceps – include gastrocnemius and soleus. We could further argue that the same principles may also apply when comparing isokinetic resistance exercise and downhill running.

In conclusion, eccentric exercise of this magnitude and type that resulted in decreased torque, DOMS and loss of ROM did not adversely influence running economy at the two intensities examined. The exercise intensity, mode and muscle groups selected as well as subjects (recreational vs. trained) tested can influence the extent of indices of muscle damage and may partially explain the controversy reported in the literature.

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