Isokinetic Eccentric Exercise of Quadriceps Femoris Does Not Affect Running Economy

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Abstract

Vassilis, P, Vassilios, B, Vassilis, M, Athanasios, JZ, Vassilis, T, Christina, K, and Yiannis, K. Isokinetic eccentric exercise of quadriceps femoris does not affect running economy. *J Strength Cond Res* 22: 1222–1227, 2008—The purpose of this study was to investigate whether running economy is affected by isokinetic eccentric exercise designed to cause muscle damage. Twenty-four young healthy men performed 120 maximal voluntary eccentric actions at each thigh's quadriceps muscle at an angular velocity of $60°\cdot s^{-1}$. The participants were then randomly divided into 2 equal groups, 1 of which exercised 24 hours later, while the other group rested. Muscle damage indicators (i.e., serum creatine kinase, delayed onset muscle soreness, and eccentric, concentric, and isometric peak torque) and running economy indicators (i.e., oxygen consumption, pulmonary ventilation, respiratory exchange ratio, respiratory rate, and heart rate during treadmill running at 2.2 and $3.3\ m\cdot s^{-1}$) were assessed prior to and 48 hours following the eccentric exercise. All muscle damage indicators changed significantly in both groups ($p < 0.05$) in a way suggestive of considerable muscle damage. Running economy indicators of the exercise group demonstrated only an elevation of respiratory rate at 48 hours ($p < 0.05$) and a tendency to lower economy compared to the resting group. It can be concluded that isokinetic eccentric exercise applied to the quadriceps femoris muscles did not affect running economy 48 hours later and that resting during this period tended to result in more economical running compared to exercising at 24 hours.

Key Words oxygen consumption, delayed onset muscle soreness, isokinetic peak torque

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Introduction

Constituting part of most athletic activities, eccentric exercise is known to result in delayed onset muscle soreness (DOMS) (26), large increases in the serum activity of muscle enzymes and oxidative stress (5,21), and reduction in performance (24). These symptoms typically begin 12 to 24 hours after unaccustomed exercise, peak after 1 to 3 days, and subside 3 to 7 days after exercise (1).

The process of the symptoms after muscle-damaging exercise seems to be affected by the activity status on the days after the exercise. Indeed, in a study in which immobilization was applied after eccentric exercise, muscle damage indicators recovered faster and there was some relief from DOMS (30), while in another study, partial immobilization had no effect on enhancing recovery of muscle function and DOMS after muscle damage induced by eccentric exercise (33). It was suggested that short-term immobilization after injury may allow newly formed granulation tissue to achieve a more rapid increase in tensile strength and that remobilization at some optimal point in the recovery period acts to accelerate the healing process, allowing a more rapid reduction of tissue swelling (33).

At the peak of symptom intensity, gait mechanics deteriorate due to altered kinematics and motor unit activation patterns (9,23), compromised range of motion around the knee, ankle, and hip (9,11), and general discomfort associated with DOMS (11). However, running economy, defined as $\dot{V}O_2$ at a constant submaximal velocity (8), has been found to be either negatively affected (4,6) or not affected (11,25) during the days after unaccustomed exercise. Additionally, anti-inflammatory medication after muscle damaging exercise seems not to affect running economy in healthy men (32).

If the activity level the days following unaccustomed exercise can affect the running economy of recreational athletes, exercise may be a factor that contributes to the effects of muscle damage on running economy. Therefore, if the influence of participating in activities the days after muscle damaging exercise on running economy is known, programs could be scheduled for recreational athletes in order to help them perform more economical and safer movements during the initial period of muscle damage. With the dearth of data and the contradictory nature of the existing data, the purpose of this study was to examine whether running economy is affected by prior isokinetic eccentric exercise and by the physical activity level of the following day.

Methods

Experimental Approach to the Problem

In order to address the primary hypothesis presented herein, healthy men with no experience in any form of structured resistance training were selected. Prior to and during their participation in the study, subjects maintained their usual nutritional and lifestyle habits but avoided any involvement in strenuous exercise activities. All subjects were assessed for muscle damage, muscle performance, and running economy pre-exercise and 24 hours and 48 hours postexercise. Subjects underwent an isokinetic quadriceps eccentric exercise session, applied on each lower limb. During the eccentric exercise, subjects performed 12 sets of 10 maximal eccentric voluntary efforts, with 2 minutes of rest between sets at an angular velocity of $60°·s^{-1}$. Subjects were then randomly separated into the exercise group ($n = 12$) or resting group ($n = 12$). The exercise group visited the venue 24 hours after the eccentric exercise to undertake an additional exercise bout, while all subjects reported for the follow-up measurement 48 hours after the eccentric exercise.

Subjects

Twenty-four healthy male recreational athletes (age, 22 ± 3 years; height, 176 ± 5 cm; mass, 74 ± 6 kg) volunteered to participate in the study. Subjects had no experience of eccentric exercise training for at least 6 months prior to the study and were not taking anti-inflammatory drugs. They were instructed to abstain from any unaccustomed strenuous exercise for at least 3 days prior to and during the data collection period. Subjects read and signed an informed consent form according to the standards of the Institutional Ethics Committee.

Procedures

Subjects visited the data collection venue on 6 or 7 occasions depending on the group to which they were assigned. The first and second visits were on consecutive days for familiarization with treadmill running and isokinetic dynamometry. Less than a week later, $\dot{V}O_2max$ was assessed during a third visit, while the forth visit, at least 2 days later, was dedicated to the collection of baseline data muscle damage and running economy indicators. The fifth visit, which took place 2 to 5 days after the fourth visit, was reserved for eccentric exercise. Subjects were then randomly separated into the exercise ($n = 12$) and resting ($n = 12$) groups. The exercise group visited the venue 24 hours after the eccentric exercise to undertake an additional exercise bout. Finally, all subjects reported for the follow-up measurement 48 hours after the eccentric exercise.

$\dot{V}O_2max$ Measurement

$\dot{V}O_2max$ was evaluated during treadmill (Powerjog GXC200; Sport Engineering Ltd., Birmingham, UK) running by using an automated gas analyzer (Vmax29; Sensormedics, Yorba Linda, CA). The gas analyzer was calibrated by using a standard mixture containing 70% nitrogen, 26% oxygen, and 4% carbon dioxide according to the manufacturer's instructions. The protocol consisted of an initial running velocity of 2.8 $m·s^{-1}$, which was increased by 0.3 $m·s^{-1}$ every 2 minutes at no inclination, until subjects reached a state of volitional fatigue. Maximal heart rate (HRmax) was measured (Polar S610; Polar Electro Oy, Kempele, Finland) at the end of the $\dot{V}O_2max$ evaluation.

Eccentric Exercise

Volunteers underwent an isokinetic exercise session, in which both thighs were exercised in random order at an angular velocity of $60°·s^{-1}$, with a 5-minute rest in between. Subjects had to accomplish 12 sets of 10 eccentric maximal voluntary actions (MVCs) of each thigh's quadriceps muscle in the seated position (i.e., 120° hip angle), as previously suggested (2,10,27). A 2-minute rest interval was incorporated between sets. Prior to eccentric exercise, subjects performed a warm-up consisting of 8 minutes of cycling on a Monark cycle ergometer (Vansbro, Sweden) at 70 rpm and 50 W, followed by 5 minutes of ordinary lower-limb stretching exercises.

An isokinetic dynamometer (Cybex Norm Lumex, Ronkonkoma, NY), previously used in similar investigations (22,26), was employed in this study. The dynamometer was calibrated weekly according to the manufacturer's instructions. Subjects were coupled to the dynamometer by visually 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 full extension and 120° of knee flexion to prevent hyperextension and hyperflexion. Gravitational corrections were made for the effect of limb and Cybex arm weight on torque measurements. Feedback on the eccentric exercise intensity and duration was automatically provided by the computer monitor of the isokinetic dynamometer. Isokinetic exercise was used because the position of the subjects could be controlled to avoid hyperextension and hyperflexion and prevent possible injuries; additionally, the subject's position on the dynamometer could be recorded accurately for the follow-up measurements. Moreover, by using the isokinetic dynamometer, the intensity and the duration of the exercise could be controlled during the eccentric exercise.

Muscle Damage Indicators

Muscle damage indicators were assessed before and 48 hours after eccentric exercise.

Creatine Kinase. Blood samples were drawn from an antecubital vein, with subjects in the seated position, into plain evacuated test tubes. The blood was allowed to clot at room temperature for 30 minutes and centrifuged at 1500*g* for

10 minutes. The serum layer was removed and frozen at –20°C until analyzed. Creatine kinase (CK) was determined spectrophotometrically in duplicate by using a commercially available kit (Spinreact, Sant Esteve, Spain).

Delayed Onset Muscle Soreness. Each subject determined soreness of each limb by self-palpation of the belly and the distal region of the vastus medialis, vastus lateralis, and rectus femoris muscles in the seated position and with the muscles relaxed. Perceived soreness was then rated on a scale ranging from 1 (i.e., normal) to 10 (i.e., very, very sore), as previously advised (7,13).

Muscle Performance. The dynamometer described above was used to evaluate the performance of each thigh's knee extensors, by measuring eccentric peak torque (EPT) and concentric peak torque (CPT) at an angular velocity of $60°\cdot s^{-1}$ as well as isometric peak torque at 60° (IPT1) and 90° (IPT2) of knee flexion. The best of 3 MVCs was recorded for EPT, CPT, IPT1, and IPT2. There were 3 minutes of rest between eccentric, concentric, and isometric modes, and their order was randomized. Details of the assessment protocol have appeared elsewhere (16).

Running Economy Indicators

Running economy was assessed before and 48 hours after eccentric exercise by measuring $\dot{V}O_2$, pulmonary ventilation ($\dot{V}e$), respiratory exchange ratio (RER), respiratory rate, and heart rate (Polar S610) during 2 submaximal treadmill running tests at 2.2 and 3.3 $m\cdot s^{-1}$, with each lasting 6 minutes and performed in random order with 5 minutes of rest in between. Running economy indicators were obtained by averaging 6 consecutive 20-second collection periods during the last 2 minutes of each test, as previously proposed (22,26).

Since temperature can affect running economy (18,28), temperature in the laboratory was kept stable during the experiment (23 ± 1°C). Additionally, volunteers used the same shoes for each running test (20).

Additional Exercise Bout

After the aforementioned warm-up and stretching routines, the exercise group was subjected to 3 isokinetic MVCs for EPT, CPT, IPT1, and IPT2 with each thigh. There were 3 minutes of rest between eccentric, concentric, and isometric modes, of which the order was randomized. Volunteers then performed 2 submaximal 6-minute treadmill runs, with 5 minutes of rest in between. The running velocities were 2.2 and 3.3 $m\cdot s^{-1}$ and selected in a random order.

Statistical Analyses

Data are presented as the mean ± *SD*. $\dot{V}O_2$max and HRmax of the 2 groups were compared through an independent *t*-test. Paired *t*-tests were utilized to examine differences between the right and left thighs in DOMS and muscle performance indicators. Since no such differences were detected, the means of the 2 thighs were used for further analysis. All measured parameters were analyzed through protocol (rest and exercise) × time (before and after eccentric exercise) analysis of variance, with repeated measures on time. Pairwise comparisons were performed through simple main effect analysis. The level of significance was set at $p \leq 0.05$.

Results

$\dot{V}O_2$max was 52.7 ± 6.9 $mL\cdot kg^{-1}\cdot min^{-1}$ and 47.1 ± 6.0 $mL\cdot kg^{-1}\cdot min^{-1}$ for the exercise and resting groups, respectively, and the corresponding HRmax was 197 ± 9 $b\cdot min^{-1}$ and 194 ± 8 $b\cdot min^{-1}$, respectively. No significant differences between groups were found for these 2 parameters.

Muscle Damage Indicators

All muscle damage indicators (Table 1) were altered significantly ($p < 0.05$) 48 hours postexercise compared to baseline values, in a way suggestive of considerable muscle damage (e.g., increases in CK and DOMS and decreases in peak torques). None of the studied parameters demonstrated significant differences between groups ($p > 0.05$).

Table 1. Muscle damage indicators at baseline and 48 hours after eccentric exercise in the group that exercised lightly and the group that rested at 24 hours (mean ± *SD*).

Indicator	Exercise group ($n = 12$) Baseline	Exercise group ($n = 12$) 48 hours	Resting group ($n = 12$) Baseline	Resting group ($n = 12$) 48 hours
CK ($IU\cdot L^{-1}$)	222 ± 149	777 ± 840*	224 ± 57	579 ± 334*
DOMS	1.0 ± 0.0	7.2 ± 1.9*	1.0 ± 0.0	6.5 ± 1.5*
EPT (N·m)	306 ± 58	193 ± 48*	318 ± 38	215 ± 46*
CPT (N·m)	207 ± 41	148 ± 37*	225 ± 16	168 ± 22*
IPT_1 (N·m)	227 ± 46	169 ± 47*	258 ± 38	167 ± 26*
IPT_2 (N·m)	203 ± 28	152 ± 22*	213 ± 18	157 ± 32*

CK = creatine kinase; DOMS = delayed onset muscle soreness; EPT = eccentric peak torque; CPT = concentric peak torque; IPT1 = isometric peak torque at 60° knee flexion; IPT2 = isometric peak torque at 90° knee flexion.

*Significantly different from baseline ($p < 0.05$).

Table 2. Running economy indicators at baseline and 48 hours after eccentric exercise in the group that exercised and the group that rested at 24 hours (mean ± *SD*).

Indicator	Exercise group ($n = 12$)		Resting group ($n = 12$)	
	Baseline	48 hours	Baseline	48 hours
$\dot{V}O_2$ at 2.2 $m \cdot s^{-1}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	27.5 ± 2.5	29.1 ± 4	28.5 ± 3.1	27.6 ± 3.4
$\dot{V}O_2$ at 3.3 $m \cdot s^{-1}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	37.3 ± 2.1	40.1 ± 4.5	37.4 ± 3.6	33.6 ± 4.9
$\dot{V}E$ at 2.2 $m \cdot s^{-1}$ ($L \cdot min^{-1}$)	50.3 ± 4.3	55.1 ± 8.6	57.8 ± 9.6	56.2 ± 9.9
$\dot{V}E$ at 3.3 $m \cdot s^{-1}$ ($L \cdot min^{-1}$)	88.5 ± 15.9	89.3 ± 17.6	89.3 ± 15.9	90.2 ± 17.6
RER at 2.2 $m \cdot s^{-1}$	0.91 ± 0.06	0.93 ± 0.07	0.93 ± 0.05	0.92 ± 0.06
RER at 3.3 $m \cdot s^{-1}$	0.96 ± 0.05	0.96 ± 0.06	1.01 ± 0.09	1.00 ± 0.07
Respiratory rate at 2.2 $m \cdot s^{-1}$ ($breaths \cdot min^{-1}$)	28.3 ± 8.3	36.2 ± 7.9*	26.0 ± 6.7	30.5 ± 9.7
Respiratory rate at 3.3 $m \cdot s^{-1}$ ($breaths \cdot min^{-1}$)	41.2 ± 10.6	43.8 ± 12.5	38.2 ± 8.3	38.0 ± 8.1
Heart rate at 2.2 $m \cdot s^{-1}$ ($b \cdot min^{-1}$)	136 ± 12	137 ± 15	147 ± 19	138 ± 17
Heart rate at 3.3 $m \cdot s^{-1}$ ($b \cdot min^{-1}$)	165 ± 12	165 ± 12	170 ± 17	164 ± 14

$\dot{V}E$ = pulmonary ventilation; RER = respiratory exchange ratio.
*Significantly different from baseline ($p < 0.05$).

Running Economy Indicators

Table 2 shows that compared to baseline, the exercise group exhibited a significant elevation ($p < 0.05$) of respiratory rate during running at 2.2 $m \cdot s^{-1}$ 48 hours postexercise, while no other running economy indicator changed significantly ($p >$ 0.05). None of the studied parameters differed significantly between groups ($p > 0.05$), although most of them tended to suggest a lower running economy in the exercise group.

Discussion

The purpose of this study was to investigate whether running economy is affected by a session of isokinetic eccentric exercise designed to cause damage of the quadriceps femoris muscles. It was found that such exercise did not affect running economy 48 hours later. An additional finding was that running at 48 hours tended to be less economical when a bout of exercise was performed 24 hours after the eccentric exercise.

The current findings are in line with published reports (11,25), in which muscle damage caused by unaccustomed exercise did not alter running economy. The current data contrast with the findings of studies in which downhill running affected running economy (4,6). The different training status of the volunteers (i.e., recreational athletes versus trained runners) may account for the observed discrepancy between studies, because running economy may be less sensitive to muscle damage in recreational athletes, as gait patterns may not be as well refined as in trained runners. The current results are also in line with a report (31) that revealed that DOMS caused by a submaximal resistance exercise of the lower extremities did not affect $\dot{V}O_2$ during 30 minutes of submaximal running. However, this type of resistance exercise provides insufficient control of intensity, duration, and rest between efforts.

Eccentric exercise performed in the current investigation was adequate to cause muscle damage in the exercised muscle groups. The magnitude of muscle damage was close to that caused by other investigators in studies of a similar experimental design. For instance, in the current investigation, CK activity and DOMS had almost the same response to eccentric exercise compared to the studies by Chen et al. (6) and Scott et al. (31), while in some cases, DOMS reported in the current study had higher values than in other comparable studies (4,11). Moreover, the absence of significant alterations in running economy after muscle damage could be attributed to the relatively low running intensity used in the current investigation. Indeed, greater running intensities (i.e., up to 85% of $\dot{V}O_2$max) were used in other studies (4,6) than in the current investigation (i.e., 75% of $\dot{V}O_2$max). The only exception was the study by Paschalis et al. (19), in which the intensity was comparable to that in the current study and in which it was also found that muscle damage had no effect on running economy. Indeed, it has been suggested that the intensity of running test influences running economy (19). Previous studies have shown that type II fibers may be more susceptible than type I fibers to injury from maximal eccentric exercise (3,15). It could be argued therefore that if muscles of the lower limbs use their lesser affected type I muscle fibers due to the low running intensity, it is possible that the running economy is not affected by the eccentric exercise.

The lack of significant changes in running economy following isokinetic resistance exercise in contrast to the majority of studies that used downhill running may also be due to different muscle recruitment patterns in the 2 exercise modes. The current eccentric knee flexion exercise resulted in damage mainly to the quadriceps muscles, with little or no effect on other muscles participating in running, such as the biceps femoris mainly and the gastrocnemius and soleus (6,9). In contrast, downhill running affects all these muscles and may thus be expected to have a greater impact upon running economy.

In general, attempts to curb the progress of muscle damage, for instance, through cryotherapy and stretching, were met with little success (12,14). To test whether physical activity following muscle damaging exercise affects running economy, exercise at 24 hours was compared with no exercise. The tendency for more economical running in the resting group is in agreement with the finding of enhanced MVC recovery with immobilization after eccentric exercise (29), which authors have attributed to an improved healing process within the contractile and noncontractile elements of the muscle fibers. These findings are also in line with the findings that muscle fiber regeneration was enhanced and that fiber disruption was less after 5 days of immobilization compared with immediate mobilization of the muscle after injury in an animal model (17). Additionally, Lehto et al. (17) found increased type I collagen synthesis after short-term immobilization, suggesting an increase in the strength of the muscle during the early stages of repair. In contrast, Zainuddin et al. (33) found that partial immobilization demonstrated no differences on recovery of muscle function and DOMS after eccentric exercise induced muscle damage, compared to a control group. These authors, however, did not rule out the effects of movement during the partial immobilization.

It can be concluded that an isokinetic eccentric exercise bout did not alter running economy 48 hours later and that resting during this period tended to result in more economical running compared to exercising at 24 hours. It could be recommended, therefore, that recreational athletes avoid participation in physical activities on the day following an unaccustomed exercise session. A short period of immobilization may be necessary for the muscle to develop sufficient tensile strength to withstand mechanical forces associated with remobilization and avoid muscle fiber rupture. On the other hand, the current results could be affected by the fact that the quadriceps femoris of both legs performed the muscle damaging exercise. If other muscle groups of the lower limb had been chosen to perform the eccentric exercise, the results might have been different. Further investigations are warranted in this area of great interest to recreational and professional athletes.

Practical Applications

In almost all sport events, running is one of the most common movements. Additionally, it is a common experience for athletes of different sport events to have muscle pain after a strenuous training program, especially when this program is unaccustomed to them. According to the findings of this study, when muscle damage occurs in an athlete after an unaccustomed exercise, resting, compared to light exercise, 24 hours after exercise will help him or her to perform more economical movements 48 hours after exercise.

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