EFFECTS OF ECCENTRIC EXERCISE ON ANAEROBIC POWER, STARTING SPEED AND ANAEROBIC ENDURANCE

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Abstract:

The aim of this study was to evaluate the effects of eccentric exercise on anaerobic power, starting speed and anaerobic endurance. The participants performed the maximum cycling sprint test (MCST) prior to eccentric exercise (ECC), 10 minutes after, as well as one hour, 24 hours, 48 hours, and one week after ECC. The peak and mean power, time to attain peak power, time of maintaining peak power and power decrease were measured in the MCST. Before and after ECC, the myoglobin concentration (Mb) in the blood plasma was measured. After ECC, a significant ($p<.05$) increase in Mb was observed. A significant ($p<.05$) decrease was noted in peak (-.92±0.42 $W \cdot kg^{-1}$) as well as in mean power (-.57±0.36 $W \cdot kg^{-1}$) immediately after ECC. A significant ($p<.05$) decrement of these indicators lasted for at least 24 hours after ECC. Eccentric exercise did not affect starting speed (time to attain peak power) and anaerobic endurance (time of maintaining peak power and power decrease during MCST).

Key words: *delayed muscle soreness, cycling, anaerobic performance, muscle power*

Introduction

Although all forms of exercise (isometric, concentric, eccentric) have the potential to cause post-exercise muscle damage, eccentric exercise can cause more acute alterations of the cytoskeleton, as well as microlesions of the muscle fibers, and have been demonstrated to induce damage to muscle fibres post exercise (Isner-Horobeti, et al., 2013; Proske & Morgan, 2001). Eccentric contractions occur when muscles extend while producing force (Proske & Morgan, 2001). Exercise-induced muscle damage (micro-injuries) due to strain inflammatory condition causes pain, reduction in joint range of motion, swelling and muscle stiffness, all of which occur at different time points within the time course of recovery. Symptoms of muscle damage occur up to 72 hours after the exercise have been reported, with recovery occurring between five to seven days (Cleak & Eston, 1992; Isner-Horobeti, et al., 2013; Kuipers, 1994). The biochemical markers of muscle damage are increased activity of creatine kinase and/or concentration of myoglobin (Mb) in blood plasma (Chen, Nosaka, Lin, Chen, & Wu, 2009; Eston, Mickleborough, & Baltzopoulos, 1995; Nottle & Nosaka, 2007; Paschalis, et al., 2005; Warren, Lowe, & Armstrong, 1999). Eccentric exercise occurs in many sports disciplines and can be observed during deceleration, e.g. downhill running (DR), landing after a vertical jump and strength exercises. Exercise-induced muscle damage may negatively affect athletic performance (Byrne, Twist, & Eston, 2004), and thus disrupt training programs.

During short (up to 60 seconds) bouts of supramaximal exercises, adenosine triphosphate and phosphocreatine (phosphogenic) and glycolytic energy systems are involved in energy production (Smith & Hill, 1991). Anaerobic performance is assessed by measurements of peak (PP) and mean power (MP). Peak power is an indicator of the phosphogenic energy system capacity (short <10 seconds supramaximal exercise), while mean power (MP) assesses capacity of phosphogenic and glycolytic energy systems (20-60 seconds duration exercises). Anaerobic power is a product of strength and speed and it is an important indicator of anaerobic performance (strength-speed-power activity). In addition to peak and mean power, starting speed and anaerobic endurance are important in many sports. Starting speed is the ability of an athlete to reach maximum speed (power) from a static state in the shortest possible time. By contrast, anaerobic endurance is the ability to maintain the highest power for as long as possible. The results of previous investigations indicated that after eccentric exercise a significant decrease in strength and power was observed (Cleak & Eston, 1992; Howell, Chleboun, & Conatser, 1993; Nottle & Nosaka, 2007). However, previous studies (Byrne, & Eston, 2002; Nottle & Nosaka, 2007) did not evaluate the effect of eccentric exercise on starting speed and anaerobic endurance. Therefore, the purpose of this study was to i) provide a comprehensive evaluation of changes in peak and mean power output during one-week long recovery after a single eccentric exercise, and ii) evaluate the effects of muscle damage on starting speed and anaerobic endurance. We hypothesized that muscle damage may reduce peak and mean power, as well as starting speed and anaerobic endurance.

Methods

The study design was approved by the Bioethics Committee of the Regional Chamber of Physicians, and procedures were carried out in accordance with Helsinki Declaration. All participants were informed about the study aim and procedures, and signed a written consent form to participate in the project. Prior to the exercise stress tests, participants underwent medical examination to exclude possible contraindications for performing maximal exercise. Participants were not allowed to use any pain medications or any treatment after eccentric exercise (downhill running: DR). All exercise tests were performed in one laboratory (air conditioned) in similar environmental conditions (21-22°C, humidity about 50-55%).

Participants

The group of participants comprised 10 healthy men aged 21.2±1.32 years. The mean body height of the participants was 179.1±4.89 cm, and the mean body mass was 79.5±14.57 kg. The mean lean body mass equaled 63.5±7.41 kg, body fat amounted to 18.3±5.19%, and body mass index was 24.3±3.15 kg·m^{-2}. The participants were physically active (light to moderate exercise ≥three times per week), but none engaged in long-distance running or performed eccentric exercise regularly. During the study, participants did not undertake any other intensive physical activity. The participants presented peak oxygen uptake (VO_2peak) of 54.1±6.13 mL·kg^{-1}·min^{-1}.

Anthropometric measurements

Body mass and body composition (lean body mass and body fat) were measured by a body composition analyzer (Jawon Medical IOI-353, Korea) using the bioelectric impedance method (eight electrodes, three measurement frequencies, tetra-polar electrode method). Body height was measured using the Martin (USA) type anthropometer with 1 mm accuracy.

Exercise tests

Twenty-four hours prior to testing participants were asked to refrain from physical activity, maintain hydration levels, and get at least six to eight hours of sleep. Participants were also asked to consume a light meal at least two hours before testing. All exercise stress tests were performed under the supervision of a sports physician. The exercise tests consisted of two parts: first, an incremental test until volitional exhaustion, and then, the experimental tests one week later. The peak oxygen uptake (VO_2peak) was determined in the incremental test. Next, on the basis of the results of the graded test, running intensity (60% VO_2peak) and speed during DR were designated. In the main part of the study, the participants performed the maximal cycling sprint test (MCST) prior to and five times (10 minutes, one hour, 24 hours, 48 hours, one week) after DR.

Familiarization session

Our participants were unaccustomed to downhill running and maximal sprinting on a cycle ergometer. Three days before experimental tests, the participants were familiarized with the technique of running on a motorized treadmill (run for five minutes) and MCST. During supramaximal sprints on the cycle ergometer, the practice effect could have occurred: results obtained in the second test were significantly higher than in the first measurement (Barfield, Sells, Rowe, & Hannigan-Downs, 2002). In order to avoid the practice effect, the familiarization with MCST was performed once prior to baseline testing, in the same manner as during experimental measurements.

Incremental test

The test was performed on a motorized treadmill (h-p Cosmos, Saturn, Germany) and started at the speed of 7.0 km·h^{-1}, which was maintained for four minutes. Then speed was increased by 1.2 km·h^{-1} every two minutes and was maintained until the participant's volitional exhaustion. Throughout the test, oxygen uptake was analyzed using the Medikro 919 (Finland) ergospirometer. The VO_2peak was considered to be either the highest registered value that did not rise despite the increasing velocity, or the peak value registered at the moment a participant finished the test.

Downhill running: eccentric exercise

Downhill running was performed at a -10% slope angle for 60 minutes at a constant speed individually determined for each participant. In DR, to control exercise intensity (60% VO_2peak), oxygen uptake was continuously measured during running (60 minutes) and recorded every 30 seconds. Exercise intensity and running speed were set at the beginning of DR. The speed was eventually corrected after the first five to six minutes of DR, and then it was kept invariable throughout the test. Mean running speed was 10.7±1.4 km·h^{-1}.

Maximal Cycling Sprint Test

The peak and mean power were measured on a cycle ergometer (Monark 824 E, Sweden) directly before DR, 10 minutes after it, and then one hour, 24 hours, 48 hours, and one week following the run. The participants performed a 20-second maximal cycling sprint with a 7.5% body mass workload. Seat height was adjusted so that the participant's leg was near complete extension at the bottom of the stroke. The test was preceded by a four-minute standard warm-up performed on the cycle ergometer (workload: 90 W), during which the participants performed two maximal accelerations, lasting five to six seconds, in the second and the fourth minute of the warm-up. The break between the warm-up and test lasted four minutes. The MCST had a stationary start, with the workload set prior to the test. During the test, participants had to achieve maximum pedaling velocity as soon as possible, and then maintain it throughout the test. The cycle ergometer was equipped with a device for measuring the speed of each revolution. The software (MCE, JBA Staniak, Poland) enabled measurement of: PP, MP, time to attain peak power (TA), time of maintaining peak power (TM), power decrease (PD) during the test, and total work (TW). Peak power, MP and TW were expressed in absolute values (W; kJ) and were also provided in relation to a participant's body mass (W·kg^{-1}; J·kg^{-1}). During the test, participants received verbal encouragement. The participants were required to remain seated during the sprint.

Biochemical analysis: evaluation of muscle damage after downhill running

Before and after downhill running, Mb concentration in blood plasma was measured using the electrochemiluminescence method (Cobas 6000, Roche-Hitachi, Japan), based on the sandwich principle implementing two different monoclonal antibodies specific for the biotin-labeled human myoglobin and ruthenium complex (Roche Diagnostics GmbH reagent kit, Germany). In order to determine the concentration of Mb, venous blood samples were drawn five minutes before the exercise tests (MCST and DR) and five minutes after its completion. The samples were put into two mL vacutainer tubes containing K2EDTA and were immediately centrifuged. After centrifugation, blood plasma samples were drawn into cryotubes and stored for no longer than four weeks at -20°C until analysis.

Visual analogue scale (VAS)

Muscle soreness was estimated by a visual analogue scale which is often used to assess pain intensity after eccentric effort (Clarkson & Tremblay, 1988; Paschalis, et al., 2005; Smith, et al., 1994). Each participant indicated a position on the scale between 0 and 10 cm, where zero meant no pain and 10 meant maximal pain. The result was read to an accuracy of one mm. Muscle soreness was evaluated while the participant rose from a chair (seat height: 45 cm), performed a knee bend and extended his lower limb at knee joint while sitting on a chair. The pain intensity evaluation was performed prior to the DR, then during each subsequent measurement taken immediately before the MCST.

Statistical analysis

Data distribution was determined with the Shapiro-Wilk test. Due to a small number of participants, and because of the lack of normal data distribution, non-parametric statistics was used. The significance of changes in the analyzed indicators was evaluated with Friedman ANOVA. The changes were found to be statistically significant if $p<.05$. The significant level of differences between the baseline level and subsequent measurements taken after downhill running (10 minutes, one hour, 24 hours, 48 hours, and one week after) was determined with the non-parametric Wilcoxon test, applying the assumption that the differences were significant at $p<.05$. Statistical analysis was conducted using STATISTICA® 8.0 (StatSoft, Inc. USA) software.

Table 1. Pain intensity experienced while extending lower limbs at knee joints, rising from a chair and performing a knee bend evaluated with the Visual Analogue Scale in subsequent measurements

Limb/movement	Measurement					
	Pre-DR	after	1 h	24h	48h	1 week
L/knee extension	0	1.2±2.16*	.9±1.32*	1.6±1.57*	.9±1.02*	0
R/knee extension	0	.9±1.30*	.7±1.07*	1.5±1.37*	.6±0.58*	.03±0.09
Rising from a chair	0	1.1±1.90*	1.2±2.09*	1.0±0.89*	.8±0.90*	0
Knee bend	0	1.7±2.06*	1.7±2.29*	2.3±1.76*	1.7±1.67*	.1±0.20

Note. Data are presented in cm as M±SD. L: left; R: right; DR: downhill running; * significant (p<.05) difference from the measurements taken prior to running.

Table 2. The level (M±SD) of variables measured in the Maximal Cycling Sprint Test in particular measurements

Variables	Measurement					
	Pre-DR	After	1 h	24h	48h	1 week
PP (W)	872.5±140.11	798.6±139.84*	811.4±134.16*	824.1±130.56*	874.0±132.28	889.6±131.13
PP (W·kg^{-1})	11.1±1.00	10.2±1.19*	10.3±1.12*	10.5±0.98*	11.1±1.02	11.2±0.87
MP (W)	747.9±110.39	702.7±110.93*	701.4±106.62*	702.3±103.48*	742.9±100.59	748.4±100.59
MP (W·kg^{-1})	9.5±0.69	8.9±0.94*	8.9±0.89*	8.9±0.78*	9.5±0.90	9.5±0.69
TW (kJ)	14.7±2.40	14.0±2.21*	14.0±2.10*	14.0±2.07*	14.5±1.88	14.9±2.01
TW (J·kg^{-1})	184.5±17.63	177.1±18.9*	176.9±17.43*	177.2±17.76*	183.6±15.79	188.8±13.91
TA (s)	3.9±0.84	4.4±1.15	4.0±1.09	3.9±1.17	4.3±1.55	4.0±1.12
TM (s)	4.0±1.12	3.1±0.68	3.5±0.75	3.1±0.85	3.6±1.07	3.4±0.72
PD (W·kg·s^{-1})	.3±0.07	.3±0.09	.3±0.06	.3±0.08	.3±0.05	.3±0.06

Note. *significant [p<.05] difference from the measurements taken prior to running; PP: peak power; MP: mean power; TW: total work; TA: time to attain PP; TM: time of maintaining PP; PD: power decrease; DR: downhill running

Results

Before downhill running, the mean myoglobin concentration in blood plasma amounted to 44.40±11.71 ng·mL^{-1}, and after DR the Mb increased significantly (p<.01) by about 160.90±99.22 ng·mL^{-1} (260.17%) in comparison to the baseline measurement. After downhill running, the subsequent measurements taken for 48 hours (starting from the measurements conducted immediately after the run) indicated a significant increase in experienced pain intensity while extending limbs at knee joint, rising from a chair and doing a knee bend (Table 1). The highest pain intensity was registered 24 hours after DR.

In comparison to the baseline level, a significant decrease in peak and mean power was observed about 24 hours after DR (Table 2). The maximal decrement of PP amounted to -.92±0.42 W·kg^{-1} (-8.3%), and decrement of MP output was -.57±0.36 W·kg^{-1} (-6.1%), which was noted 10 minutes after the DR. Forty-eight hours after downhill running and one week after it, the observed differences in the level of PP and MP were not significantly different in comparison to the baseline level (Table 2). Similar changes during recovery were also observed in TW (Table 2). A week after DR, a small, non-significant (about 2%) super-compensation of PP was observed; in the case of MP, it returned only to its baseline values. No significant changes in TA and TM were noted during recovery or in PD during the test following downhill running (Table 2).

Discussion and conclusions

The aim of this study was to evaluate the effects of eccentric exercise on anaerobic power, starting speed and anaerobic endurance. The novel findings of this study were the effects of muscle damage on starting speed and anaerobic endurance. Time to attain peak power was similar in all performed MCST, which indicates that eccentric work (downhill running) does not adversely affect starting speed. Time of maintaining peak power was similar in subsequent measurements following DR, which confirms that eccentric work does not affect participant's anaerobic endurance. The results of our study indicated that the observed power decrement following DR was not the result of muscle fatigue due to a long-term running: the level of PD during the Wingate Test remained mostly unchanged in subsequent measurements, which was presented in previous studies (Inbar, Bar-Or, & Skinner, 1996; Nottle & Nosaka, 2007).

The results of our study confirmed the results of previous studies (Byrne & Eston, 2002; Nottle

& Nosaka, 2007), stating that PP as well as MP decreased significantly after eccentric exercise. Previous investigations (Byrne & Eston, 2002; Nottle & Nosaka, 2007) indicated significant decrement of peak power, but the magnitude of power loss and time of recovery noted in these studies was different. In our study, we observed a similar decrease in peak (8%) and mean power (6%) compared to the reduction in power reported by Nottle and Nosaka (2007), but lower than reported by Byrne and Eston (2002) (13-18%). The decrease in muscle power noted in our study lasted much longer (more than 24 hours), compared to those reported (30 minutes) by Nottle and Nosaka (2007). Byrne and Eston (2002) observed the decrement of power after eccentric exercise for two days. Differences between our results and the results obtained by Byrne and Eston (2002) and Nottle and Nosaka (2007) may be explained in a few possible ways.

First of all, the difference in results may have been caused by the implementation of different research protocols. Consequently, differences in protocols may induce different degrees of muscle damage and thus, at the same time, affect the results of anaerobic power measurements in different ways. Our results indicate that further research is necessary to determine the degree to which reduction in muscle function and muscle damage are influenced by aspects of eccentric exercise modality. Chen, Nosaka and Tu (2007) made similar observations regarding the evaluation of running economy and reported that changes in running economy after DR may be the result of research procedure (slope angle). These investigators observed that a greater slope angle induced greater muscle damage, and thus, may have a direct influence on the markers of muscle damage post DR. Similar to the investigation by Nottle and Nosaka (2007), we induced muscle damage with downhill running. In contrast, Byrne and Eston (2002) evoked muscle damage by performing the eccentric phase of the barbell squat exercise with a load corresponding to 80% of one repetition maximum. Meanwhile, during the anaerobic power measurement (MCST; Wingate Test) on an ergometer, muscles that have not been previously damaged during eccentric exercise may be involved. Thus, as an effect, the loss of power after eccentric work may be small (Nottle & Nosaka, 2007).

Secondly, inclusion criteria to the study may have significant influence on the final results. The participants of Nottle and Nosaka's study (2007) were involved in football and field hockey. These sports incorporate a large eccentric component. Subjects engaging in regular eccentric training programs are less susceptible to muscle damage than untrained people (Flann, LaStayo, McClain, Hazel, & Lindstedt, 2011; Isner-Horobeti, et al., 2013), but Flann et al. (2011) reported that both trained and untrained participants experienced muscle rebuilding post eccentric training. The participants of our study were unaccustomed to the task of downhill running and did not train eccentrically before the experiment. The limitation of our study is an absence of control group and/or concentric exercise group. Our study aimed to evaluate the effects of eccentric exercise on anaerobic performance, but perhaps similar results could be obtained after running which incorporates both concentric and eccentric components (e.g. level or uphill running).

Muscle damage is often induced by downhill running in laboratory conditions (Chen, et al., 2007; Chen, et al., 2009; Nottle & Nosaka, 2007). Downhill running aimed at causing experimental muscle damage is usually performed at a slope angle ranging from 7 to 16% (Braun & Dutto, 2003; Chen, et al., 2009; Nottle & Nosaka, 2007) and for this reason our participants ran at a -10% slope angle. An increase in the activity of creatine kinase (Eston, et al., 1995; Nottle & Nosaka, 2007; Paschalis, et al., 2005; Warren, et al., 1999) or in Mb concentration in blood plasma is commonly observed after eccentric exercise (Chen, et al., 2009). The acute reduction in muscular function (decrease of power) and the increase in blood levels of myoglobin are common markers of exercise-induced muscle damage (Warren, et al., 1999). Another marker of muscle damage is muscle soreness, but the Visual Analogue Scale provides a weak correlation with changes in muscle function following muscle damaging events both in terms of magnitude and time course (Warren, et al. 1999). Consequently, we measured changes in Mb concentration post eccentric exercise as a strategy for a more accurate indication of muscle damage in comparison to the VAS.

The MCST used in this study was a modified version of the Wingate Test. The differences were related to shortened test time (20 seconds vs. 30 seconds in the original test) and the form of test start. In our study, we applied a stationary start with a load determined beforehand in comparison to the flying start in the original Wingate Test. Thus, we were able to measure some other indicators during the test. Time to attain peak power indicates the starting speed of a participant, i.e. the time necessary to attain peak power output starting from a static position. Another indicator analyzed in our study is time of maintaining peak power, which is an indicator of anaerobic endurance. The effects of muscle damage on these indicators have not been evaluated after long-term DR in previous studies.

The practice effect described in cycle ergometer tests for measuring power output should also be considered during the interpretation of the results (Barfield, et al., 2002). The results obtained by Barfield et al. (2002) showed that the values of maximal power output achieved in the Wingate Test were significantly higher in the second than in the first attempt. Barfield et al. (2002) and Driss and Vandewalle (2013) suggested that at least one cycling sprint measurement should be performed prior to baseline measurements when accurate assessments of peak power are needed. However, Martin, Diedrich, and Coyle (2000) demonstrated that active men require two familiarization sessions. In our study, during a familiarization session the participants performed two maximal sprints (five to six seconds) during the warm-up followed by a 20-second sprint. Moreover, the participants performed, as a part of the warm-up, additional two sprints (five to six seconds) during baseline testing. Hence our participants were exposed to ample practice throughout the familiarization process. Therefore, it is likely that the order of performing the MCST did not influence our results.

Eccentric exercise induced a significant decrease in peak power output measured in the maximal cycling sprint test. After a single acute downhill running, the decrease in power output (peak and mean) and total work may last for at least 24 hours. Eccentric work does not affect starting speed or anaerobic endurance evaluated in cycling sprint tests.

The significant decrease in power output noted in our study, which lasted at least 24 hours after the eccentric exercises, may adversely affect anaerobic performance during recovery. This should be taken into account when planning training sessions for athletes, as well as when applying biological regeneration treatment aimed at shortening anaerobic power recovery after eccentric exercise. Coaches and athletes can implement the training of starting speed and/or anaerobic endurance after eccentric exercise, as the results of our study indicated that eccentric exercise did not influence starting speed and/or anaerobic endurance.

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