

Effect of creatine loading on neuromuscular fatigue threshold

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Stout, Jeffrey, Joan Eckerson, Kyle Ebersole, Geri Moore, Sharon Perry, Terry Housh, Anthony Bull, Joel Cramer, and Ash Batheja. Effect of creatine loading on neuromuscular fatigue threshold. *J. Appl. Physiol.* 88: 109–112, 2000.—The purpose of this investigation was to determine the effect of creatine (Cr) loading on the onset of neuromuscular fatigue by monitoring electromyographic fatigue curves from the vastus lateralis muscle using the physical working capacity at the fatigue threshold (PWC_{FT}) test. Using a double-blind random design, 15 women athletes [mean age 19.0 ± 2.0 (SD) yr] from the university crew team received a placebo (*n* = 8; 20 g glucose) or Cr (*n* = 7; 5 g Cr monohydrate + 20 g glucose) four times per day for 5 consecutive days. Analysis of covariance was used to analyze the data (covaried for presupplementation PWC_{FT} values). The adjusted mean postsupplementation PWC_{FT} value for the Cr group (mean = 186 W) was significantly (*P* < 0.05) higher than that of the placebo group (mean = 155 W). These findings suggest that Cr loading may delay the onset of neuromuscular fatigue.

ergogenic aid; electromyography; cycle ergometry; muscle fatigue

A NUMBER OF INVESTIGATIONS have used surface electromyographic (EMG) procedures to identify the power output associated with the onset of neuromuscular fatigue (NMF) during cycle ergometry (3, 4, 7–9, 14, 21). NMF is typically characterized by an increase over time in the electrical activity of the working muscles (2, 4, 14, 15). Moritani et al. (15) suggested that the fatigue-induced increase in EMG amplitude is a result of progressive recruitment of additional motor units (MU) and/or an increase in the firing frequency of MUs that have already been recruited. Theoretically, work bouts at power outputs at or below the NMF threshold can be maintained continuously without EMG evidence of fatigue (i.e., no significant increase in EMG amplitude over time).

DeVries et al. (3, 4) developed an incremental cycle ergometer test called “the physical working capacity at the fatigue threshold” (PWC_{FT}), which utilizes EMG fatigue curves to identify the power output that corre-

sponds to the onset of the NMF threshold. The PWC_{FT} represents the highest power output that results in a nonsignificant (*P* > 0.05) increase in the electrical activity of the thigh muscles over time. Whereas the PWC_{FT} test has been shown to be reliable (2, 4), valid (2), and sensitive to changes in fitness level (2), the physiological mechanism responsible for the increase in EMG amplitude over time during a fatiguing task is unknown. Two potential mechanisms, however, include the accumulation of metabolic by-products (lactate, H⁺, P_i, and ammonia) and/or the depletion of stored energy substrates [ATP, phosphocreatine (PCr), and glycogen] (13). Housh et al. (8, 9) have reported that manipulation of blood acid-base balance with ammonia chloride and sodium bicarbonate, as well as glycogen depletion and supercompensation, did not affect the onset of NMF as measured by the PWC_{FT} test. However, McCartney et al. (12) have suggested that “alterations in the blood acid-base state have little influence on muscle pH.” In addition, there is evidence to suggest that skeletal muscle PCr may serve as a temporal energy buffer as well as a modulator of glycolysis and, therefore, may influence NMF (22). The effect of PCr manipulation on EMG fatigue curves, however, is unknown. Therefore, the purpose of the present study was to determine the effect of Cr loading on the onset of NMF, as measured by the PWC_{FT} test in women athletes.

METHODS

Subjects. Fifteen female members of the university crew team [age 19.0 ± 2.0 (SD) yr] volunteered as subjects for this investigation. All procedures were approved by the Institutional Review Board before the initiation of the study, and each subject was advised of any possible risks before providing informed consent.

Supplementation protocol. None of the subjects had ingested Cr, or any other dietary supplements, for a minimum of 12 wk before the initiation of the study. During the course of the study, the subjects were asked to maintain their current dietary patterns and abstain from other nutritional supplements, nonprescription drugs, and caffeine. After pretesting, the subjects were randomly assigned to one of two treatment conditions using a double-blind design: 1) 20 g of flavored dextrose powder as a placebo (Pl, *n* = 8); or 2) 5.0 g of Cr monohydrate plus 20 g of dextrose in a flavored powder blend (Cr, *n* = 7) (Creatine Edge Effervescent, Fortress Systems, Omaha, NE). The powders, identical in taste and appearance, were dissolved in 16 oz of water and ingested four times per day for 5 consecutive days before posttesting.

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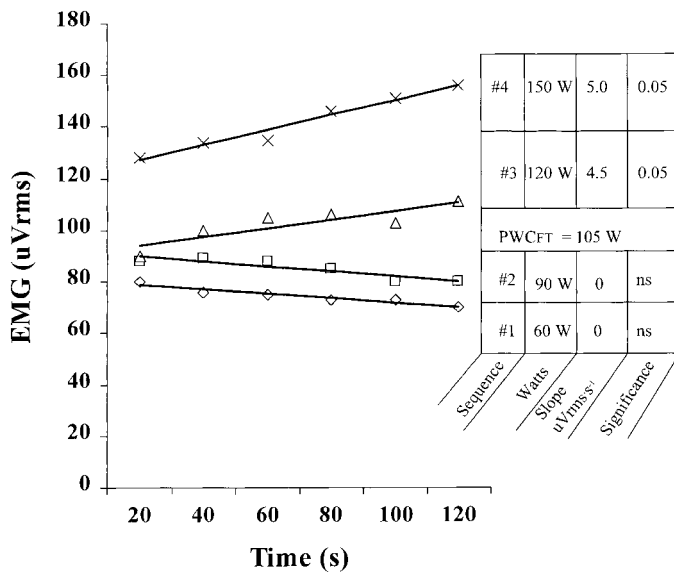


Fig. 1. Illustration of method used for determining physical working capacity at fatigue threshold (PWC_{FT}) for subject 7 in creatine group. EMG, electromyographic voltages; NS, not significant; uVrms, root mean square EMG amplitude.

Electrode placement and EMG instrumentation. A bipolar (2.54-cm center-to-center) surface electrode (Quinton Quick prep silver-silver chloride) arrangement was placed on the right thigh over the lateral portion of the vastus lateralis (VL), midway between the greater trochanter and the lateral condyle of the femur. The reference electrode was placed over the iliac crest. Interelectrode impedance was kept below 2,000 Ω by careful abrasion of the skin. The EMG signal was preamplified (gain: ×1,000) by using a differential amplifier (EMG 100, Biopac System, Santa Barbara, CA). The EMG signal was sampled at 1,000 points/s and filtered at 10–500 Hz. The root mean square EMG amplitude values were calculated for the 10-s time frame for each sample taken (MP100, Biopac Systems).

Determination of PWC_{FT}. The PWC_{FT} values were determined from the VL muscle by using the protocol of deVries et al. (3). Figure 1 illustrates how the PWC_{FT} was determined using the data from subject 7 in the Cr group (Table 1). The subjects began pedaling (with toe clips) at 60 W (70 rpm) on a calibrated, electronically braked cycle ergometer (Corval 400, Quinton Instruments, Seattle, WA). The power output was then increased by 30 W every 2 min until the subject could no longer maintain 70 rpm. During each 2-min interval, six 10-s EMG samples were recorded from the VL. The PWC_{FT} was determined by averaging the highest power output that resulted in a nonsignificant ($P > 0.05$; single-tailed t -test) slope value for the EMG amplitude vs. time relationship, with the lowest power output that resulted in a significant ($P < 0.05$) slope value (Fig. 1).

Reliability of the PWC_{FT} was determined by using a subsample of subjects ($n = 11$) measured 7 days apart. The test-retest intraclass correlation coefficient (R) was 0.94 (SE ± 6 W), which is similar to values reported by deVries et al. (2, 3) in older ($R = 0.976$) and younger male subjects ($R = 0.947$). In addition, the test-retest mean difference for the PWC_{FT} values 0.5 W was not statistically significant ($t = 0.09$; $P > 0.05$).

Statistical analysis. Changes in body weight (BW) as a result of supplementation were analyzed by using a 2 × 2 [treatment (Pl, Cr) × time (pretest, posttest)] mixed factorial ANOVA. Differences in the mean posttest PWC_{FT} value were determined by using analysis of covariance, with pretest PWC_{FT} serving as the covariate. Data were considered significantly different when the probability was $P \leq 0.05$.

RESULTS

The descriptive characteristics of the subjects, as well as the changes in BW and PWC_{FT} for the two groups, are shown in Table 1. There were no significant changes in BW from pretesting to posttesting for either group. However, the adjusted mean posttest PWC_{FT} value for the Pl group (mean = 155 W) was significantly less than that of the Cr group (mean = 186 W).

Table 1. Characteristics of the subjects ($n = 15$)

Subject	Age, yr	Height, cm	BW-Pre, kg	BW-Post, kg	PWC _{FT} -Pre, W	PWC _{FT} -Post, W
<i>Placebo group</i>						
1	18	163	75.5	75.0	165	135
2	19	165	51.4	51.8	135	135
3	19	167	56.4	56.0	135	135
4	20	167	59.0	59.6	165	165
5	17	170	80.5	81.8	135	165
6	19	164	70.5	69.9	165	165
7	21	160	60.5	59.0	105	105
8	19	163	56.0	56.0	165	165
Mean ± SD	19.0 ± 1.2	164.9 ± 3.1	63.7 ± 10.4	63.6 ± 10.6	146.3 ± 22.3	146.3 ± 22.3
<i>Creatine group</i>						
1	17	172	74.3	76.4	165	225
2	21	154	66.7	68.2	165	195
3	20	163	67.3	65.0	195	225
4	22	159	64.0	64.5	165	195
5	18	166	78.9	78.7	225	225
6	18	167	62.7	63.4	165	165
7	20	178	65.5	64.7	105	135
Mean ± SD	19.4 ± 1.8	165.6 ± 8.0	68.5 ± 5.9	68.7 ± 6.3	169.3 ± 36.4	195* ± 34.6

PWC_{FT}, physical working capacity at fatigue threshold; BW, body weight; Pre, before treatment; Post, after treatment. * Mean PWC_{FT}-Post values significantly different from mean PWC_{FT}-Pre values ($P < 0.05$).

DISCUSSION

Recent investigations (6, 10) using male subjects have shown that Cr loading (20 g/day) for 5 days significantly elevated whole muscle Cr stores by an average of 20%, with as much as 20% stored in the form of PCr. Vandenberghe et al. (20) demonstrated a 6% increase in muscle PCr concentration in college-age women (19–22 yr old) after 4 days of Cr loading. The female subjects in the present study (Table 1) were similar in age (18–21 yr old) and closely followed the Cr loading regimen used in the study by Vandenberghe et al. (20) (5 g, four times per day for 5 days). Therefore, although muscle PCr levels were not directly measured in the present study, the results of previous investigations (6, 10, 20) suggest that it is likely that the Cr loading resulted in an increase in muscle PCr concentration.

Several studies that have examined the ergogenic effect of Cr loading on performance by using supramaximal workloads on a cycle ergometer have reported significant increases in total work during both single and multiple bouts of exercise (1, 11, 17, 22). Recently, Jacobs et al. (11) and Prevost et al. (17) demonstrated significant increases in time to exhaustion (8.5 and 24%, respectively) during cycle ergometry at 125 and 150% maximal oxygen consumption rate after Cr loading in physically active men and women. Prevost et al. hypothesized that Cr loading increased exercise capacity and diminished the exercise-induced rise in plasma lactate levels by delaying anaerobic glycolysis. In contrast, Febbraio et al. (5) demonstrated no significant differences in time to exhaustion and intramuscular lactate levels during cycle ergometry at 115–120% of maximal oxygen consumption rate after Cr loading in untrained men.

Fewer studies have been conducted to determine the effects of Cr loading on submaximal exercise performance (16, 18). Nelson et al. (16) recently reported that Cr loading in male and female athletes (age range 21–27 yr) resulted in a 12% increase in the ventilatory threshold as well as a decrease in blood lactate and ammonia concentrations during incremental cycle ergometry. In contrast, Stroud et al. (18) reported that Cr loading had no effect on respiratory gas exchange or blood lactate accumulation during incremental treadmill exercise in physically active men. Discrepancies in the literature regarding the effects of Cr loading on performance may be attributed to the highly variable interindividual response in muscle Cr retention as a result of Cr loading (1, 6). Recently, Casey et al. (1) demonstrated a positive relationship ($r = 0.71$, $P < 0.05$) between anaerobic exercise performance during cycle ergometry and the magnitude of muscle Cr retention from Cr loading, and they concluded that the improvement in anaerobic performance was critically dependent on the magnitude of muscle Cr retention following loading.

McClaren et al. (13) have suggested that a decrease in muscle pH, as a result of the accumulation of H^+ or intra- and extracellular ammonia, may be responsible

for fatigue-induced increases in MU recruitment and the corresponding increase in EMG amplitude. In agreement, Taylor et al. (19) also found that, for incremental cycle ergometry, the accumulation of plasma lactate and ammonia was associated with an increase in EMG amplitude measured from the rectus femoris muscle. Therefore, there is evidence to suggest that a reliance on anaerobic glycolysis leads to an increase in EMG amplitude from the working muscles as a result of changes in muscle and blood lactate levels and the corresponding decrease in pH.

In the present study, Cr loading resulted in a delay in the onset of NMF (as measured by the PWC_{FT} test), which may have been due to the effect of elevated muscle PCr on the transition from aerobic to anaerobic metabolism. Prevost et al. (17) and Volek and Kraemer (22) have hypothesized that increasing muscle PCr content by Cr loading may decrease the reliance on anaerobic glycolysis, reduce intramuscular lactate accumulation, and, therefore, delay the onset of fatigue. Thus the results of the present study suggest that during incremental cycle ergometry Cr loading may delay the onset of NMF and the fatigue-induced increase in EMG at submaximal power outputs by reducing the reliance on anaerobic glycolysis and attenuating the accumulation of lactate and ammonia in the working muscles and blood.

In summary, Cr loading resulted in a significantly higher PWC_{FT} value (186 W) compared with a PI (155 W), indicating that Cr loading may delay the onset of NMF during incremental cycle ergometry in female athletes. The delay in NMF may have been due to augmented PCr levels in the muscle, which may have resulted in a greater capacity to delay anaerobic glycolysis (16, 17, 22). Future studies that would directly measure muscle PCr, lactate, and ammonium levels are warranted to validate these results.

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