Effect of Creatine Supplementation on Aerobic Performance and Anaerobic Capacity in Elite Rowers in the Course of Endurance Training

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The effect of oral creatine supplementation on aerobic and anaerobic performance was investigated in 16 elite male rowers during 7-day endurance training. Before and after the daily ingestion of 20 g creatine monohydrate for 5 days (Cr-Group, \(n=8\)) or placebo (Pl-Group, \(n=8\)), subjects performed two exercise tests on a rowing ergometer: (a) incremental exercise consisting of 3-min stage durations and increased by 50 W until volitional exhaustion; (b) an all-out anaerobic exercise performed against a constant load of 7 W/kg. Heart rate and blood lactate concentrations were determined during exercise and recovery. Maximal power output did not significantly differ after the treatment in either group. The mean individual lactate threshold rose significantly after Cr treatment from 314.3 ± 5.0 W to 335.6 ± 7.1 W (\(p<.01\)), as compared with 305.0 ± 6.9 W and 308.9 ± 5.9 W (ns), before and after placebo ingestion, respectively. During the anaerobic test, the athletes supplemented with creatine were able to continue rowing longer (mean increase, 12.1 ± 4.5 s; \(p<.01\)) than Pl-Group (2.4 ± 8.2 s; ns). No significant differences were found between groups in blood LA after the all-out exercise. The results indicate that in elite rowers, creatine supplementation improves endurance (expressed by the individual lactate threshold) and anaerobic performance, independent of the effect of intensive endurance training.

Key Words: creatine, progressive exercise, lactate threshold, anaerobic performance, endurance training

Introduction

Creatine and phosphocreatine play an important role in skeletal muscle metabolism during exercise. Phosphocreatine (PCr) availability is essential to perform a short-duration, high-power exercise, because depletion of PCr content in the muscle cells results in an inability to maintain the required rate of adenosine triphosphate (ATP) resynthesis (9, 19, 21). Moreover, the availability of free creatine in the muscle plays a central role in the control of PCr resynthesis, particularly in the post-exercise period (17, 23, 30).
Creatine (Cr), a natural nutrient of animal origin, is considered an effective nutritional ergogenic aid enhancing physical performance. As such it has been commonly used, especially in sports disciplines involving high intensity intermittent exercise. It was reported that oral creatine administration for a few days in a dose of 20 g daily causes a significant increase (by approximately 20%) of the total creatine pool in human skeletal muscles (2, 8, 10, 18).

However, the effect of creatine supplementation on exercise performance still remains a matter of discussion. The beneficial effect of creatine on the ability to perform the series of repeated bouts of short duration high-intensity exercise has been reported (2, 4, 7, 8, 38), but some other findings did not confirm the ergogenic effect of creatine on the anaerobic capacity (6, 12, 15, 24, 26).

The results of the studies concerning the influence of creatine supplementation on aerobic capacity are also inconsistent. Endurance performance appears to be rather unaffected by creatine treatment. According to some authors (1, 38), oral Cr intake does not affect an ability to perform a long-lasting submaximal exercise or oxygen uptake, ventilatory gas exchange indices, and blood lactate concentration during a progressive exercise and the recovery post-exercise period (16, 35). On the other hand, McNaughton et al. (22) demonstrated significant enhancement of power output during 1.5 to 5 min of exhaustive exercise on a kayak ergometer due to creatine loading. A few studies assessing the effect of creatine treatment on the rowers’ performance have shown no change in aerobic or anaerobic capacity in rowers (13, 36) and an improved time of rowing but on the non-typical distance of 1000 m (28).

The apparent inconsistency among the effects of oral creatine supplementation found in the literature might be a result of the variety of protocols and/or specific groups of subjects (trained or untrained) used to investigate these effects. It should be emphasized that positive ergogenic effects of Cr action have been generally found under laboratory conditions but not in elite athletes during their heavy training or the competition period (25).

The aim of the present study was, therefore, to reinvestigate an influence of creatine ingestion on both the aerobic and anaerobic performance in elite rowers in the course of endurance training. Although the aerobic capacity has been acknowledged as a principal factor determining sport results in rowing, the contribution of anaerobic capacity seems to be important for rowers as well, since the anaerobic energy supply during a 2000-m rowing race amounts to approximately 20–25% of the total energy expenditure during competition (33, 37). For many years the anaerobic threshold has been widely accepted in sports medicine practice as a specific, valid indicator of the cardiorespiratory endurance performance (20, 29, 31). Furthermore, it has been considered one of the most predictive indices of the competition performance in rowers (32, 33, 37). Thus, in this study the lactate anaerobic threshold and the maximal power output have been assumed to be indices of aerobic endurance performance, whilst the anaerobic capacity has been estimated as the time to maintain the maximal power at the maximal lactate concentration.

**Material and Methods**

**Subjects**

Sixteen male elite rowers volunteered for this study. The subjects’ age ranged from 20 to 31 yrs. All of them have been involved in regular endurance training programs
for several years, obtaining 2 training sessions per day. Details of the risks, benefits, and experimental procedure of the study were provided for each subject before obtaining his written informed consent. The investigation was performed before and after a 7-day intensive endurance training (a preparatory period of the year’s training cycle), with a similar training regime of two training sessions a day for each rower. All athletes maintained the same normal diet. The subjects, randomly assigned to two groups, ingested in a double-blind manner either creatine monohydrate in a dose of 20 g per day (Cr-Group, \( n = 8 \)) or placebo—that is, 20 g glucose per day (Pl-Group, \( n = 8 \)) for 5 consecutive days in four equal doses daily. Both the creatine and placebo were given as an identical pharmaceutical wafers to make them indistinguishable for subjects. Basic anthropometric characteristics and some maximal exercise data for both groups measured prior to creatine supplementation are presented in Table 1. In both Cr- and Pl-Group no significant change in body mass was noticed during the observation period.

### Table 1  Descriptive Characteristics of Subjects (\( N = 16 \))

<table>
<thead>
<tr>
<th>Variable</th>
<th>Placebo group</th>
<th>Creatine group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.5 ± 0.5</td>
<td>25.3 ± 1.7</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>90.5 ± 1.1</td>
<td>95.1 ± 1.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>194.3 ± 2.1</td>
<td>193.9 ± 2.1</td>
</tr>
<tr>
<td>( \text{VO}_{2\text{max}} ) (L · min(^{-1}))</td>
<td>5.53 ± 0.08</td>
<td>5.82 ± 0.13</td>
</tr>
<tr>
<td>( \text{VO}_{2\text{max}} ) · kg(^{-1}) (ml · min(^{-1}) · kg(^{-1}))</td>
<td>61.9 ± 1.4</td>
<td>61.0 ± 1.2</td>
</tr>
<tr>
<td>HRmax (beats · min(^{-1}))</td>
<td>187.9 ± 3.1</td>
<td>185.5 ± 1.6</td>
</tr>
</tbody>
</table>

*Note. Values are expressed as means ± SEM. \( \text{VO}_{2\text{max}} \): maximal oxygen uptake; HRmax: maximal heart rate.*

### Experimental protocol

Before and after creatine or placebo ingestion, subjects performed two exercise trials (1 day apart) on a rowing ergometer (Concept II, USA): (a) an incremental progressive exercise test starting from 220 W for 3 min and increased by 50 W every 3 min until the subjects felt exhausted, with the workloads separated by 40-s breaks for blood sampling; (b) an all-out anaerobic exercise performed with a constant load of 7 W/kg body weight.

Heart rate (HR) was recorded continuously during exercise using Sport Tester (PE 3000, Oulu, Finland). Blood lactate concentration (LA) was determined by the enzymatic method using Miniphotometer-8 (Dr B. Lange GmbH, Berlin, Germany) in arterialized capillary blood samples taken from the ear lobe after each exercise load during the incremental test and in the 3rd, 5th, and 30th min after termination of the anaerobic test.

Lactate anaerobic threshold at the blood lactate of 4 mmol · L\(^{-1}\) (LAT-4 mM) was detected for each individual by means of linear interpolation from the exponential increase in blood (LA) during the incremental exercise plotted versus workload.
The individual anaerobic threshold (LAT-log) was determined by the log-log transformation method of Beaver et al. (3). The threshold workload was assessed from the intersection of the two linear segments (log LA concentration vs. log exercise load; Figure 1).

**Statistics**

All data are reported as means with standard errors (SEM). Significance of creatine or placebo effects at 7 levels of exercise power output during an incremental test was analyzed by $2 \times 2 \times 7$ ANOVA for repeated measures. An analysis of variance with repeated measures design was also used for the all-out anaerobic test. Paired Student’s $t$ test was used for post hoc analyses in the event of a significant $F$ ratio. Significance was set at the .05 level of confidence.

**Results**

After the 7-day period of endurance training, a significant decrease in HR was found during the progressive exercise at submaximal intensities of 320 and 370 W only in the controls (Pl-Group; $p < .05$). In the Cr-Group no significant changes in HR were noted during this type of exercise, as compared to the pre-treatment conditions. The maximal power output determined during the incremental exercise test did not differ significantly between the groups, although within the observation period, it seemed to increase more in Cr-Group (from 492.5 ± 9.7 W to 507.2 ± 8.5 W; $p = .047$) than in Pl-Group (from 474.1 ± 11.3 W to 482.0 ± 7.5 W; $p = .262$).
Changes in blood (LA; Figure 2) had revealed a similar exponential increase during the incremental exercise both in Pl- and Cr-Group. At higher workloads the significant decrease in blood LA accumulation was observed after 7 days of training in both groups. This effect occurred at lower exercise intensity (370 W) in Cr-Group than in Pl-Group. The maximal blood (LA) was lowered in Pl-Group ($p < .05$) and it did not differ significantly in Cr-Group.

The lactate threshold detected at blood lactate concentration of 4 mmol/L (LAT-4 mM) was not changed by the 7-day endurance training in either group (Figure 3). However, the mean individual threshold (LAT-log) shifted to higher work intensity after creatine loading (from 314.3 ± 5.0 W to 335.6 ± 7.1 W; $p < .01$), whilst in the placebo group, only a small, insignificant increase was noted (from 305.0 ± 6.9 W to 308.9 ± 5.9 W). In addition, the mean blood (LA) detected at the LAT-log was significantly higher after creatine than placebo treatment ($p < .02$).

Figure 2 — Changes in blood lactate concentrations during progressive exercise before (open symbols) and after (closed symbols) 5 days of placebo (20 g glucose · day$^{-1}$) or creatine (20 g · day$^{-1}$) treatment. Values represent means and SEM. *Significant differences between pre- and post-trial ($p < .05$).
Figure 3 — Threshold exercise intensity at LAT-4mM or LAT-log, and average blood lactate concentrations measured at LAT-log before (open bars) and after placebo (gray bars) or creatine (black bars) treatment. Means and SEM are given. Asterisks denote significant differences between pre- and post-trial: *$p < .05$, **$p < .01$. 
During the anaerobic test, the Cr-treated subjects were able to continue rowing longer than those from the Pl-Group, as illustrated in Figure 4. The mean increase in time to exhaustion was $12.1 \pm 4.5$ s in Cr-Group ($p < .01$), and $2.4 \pm 8.2$ s in Pl-Group (ns). No significant effects of training and/or creatine loading were found on blood (LA) during the recovery after the all-out exercise test in either group (Figure 4).

**Figure 4** — Time to exhaustion during all-out anaerobic exercise and recovery blood lactate concentrations before (open bars) and after placebo (gray bars) or creatine (black bars) treatment. Means and SEM are given. **Significant differences between pre- and post-trial ($p < .01$).

Discussion

The results of the present study indicate that in the elite rowers, for 7-day endurance training, 5 days of creatine supplementation (20 g daily) improves their endurance
as well as anaerobic capacity. The power output corresponding to the lactate anaerobic threshold, measured during an incremental exercise on rowing ergometer, has been commonly accepted as the most predictive parameter of rowers’ performance (33, 37). Thus, the shifting of the individual lactate threshold (LAT-log) towards higher work intensities after creatine supplementation strongly suggests the beneficial effect of creatine ingestion on endurance performance. Moreover, a trend towards a higher increase in the maximal power output after creatine, as compared to the placebo, was also observed in our study. In most studies, oral creatine intake did not improve the ability to perform a long-lasting intensive exercise (1, 36, 38), or modified the maximal oxygen uptake, circulatory, metabolic, and ventilatory responses to the progressive exercise test (14, 16, 35). The present data are in agreement with the results reported by McNaughton et al. (22) and Rossiter et al. (28), demonstrating the positive influence of oral creatine supplementation on the aerobic performance in kayakers and rowers, respectively. Since the creatine treatment protocol has been similar in the above cited studies, the various exercise test protocols and different methods applied for endurance level estimation might be responsible for these inconsistent results.

It should be emphasized that, in this study, the effects of creatine supplementation were evaluated in highly trained, elite athletes, during their intensive endurance training. Typical effects of this type of training—a significant decrease in HR and in blood LA concentration at submaximal workloads of the progressive exercise test—have been noted in the present study, although the observation period was only 7 days. The marked attenuation of blood LA accumulation was found in both Pl- and Cr-Group probably as a result of training, but this effect occurred earlier—that is, at lower exercise intensities approximating the LAT-log, in creatine-treated athletes than in the placebo group. Consequently, a significant increase in the individual lactate threshold (LAT-log) has been only ascertained in the athletes supplemented with creatine. This finding indicates that the influence of creatine occurs in the background of the training effects. Balsom et al. (2) have also demonstrated a decrease in the muscle LA content after creatine ingestion, although their subjects performed a different type of work: a short-duration, high-intensity exercise. In the present investigation a significant increase was found in the mean blood LA concentration corresponding to the individual LAT in the Cr-Group. It may be assumed that this effect resulted from the rise of the LAT work intensity after creatine loading.

It seems that creatine ingestion does not affect the 4 mM lactate threshold, which is usually found at higher exercise intensities than the individual anaerobic threshold (11, 32). The similar pattern of blood LA changes within the range of LAT-4 mM threshold work intensities during observation period in both groups of athletes may explain the failure in altering the 4 mM lactate threshold by creatine loading.

It is worthwhile to mention that the individual anaerobic threshold (LAT-log), which increased significantly after creatine ingestion in contrast to the LAT-4mM, defines the workload at the maximal lactate steady state but not the fixed anaerobic threshold of 4 mmol · L⁻¹, as appeared from the lactate kinetics model presented by Stegmann and Kindermann (32). Furthermore, the individual anaerobic threshold was found to correspond more closely to the muscle lactate accumulation during exercise of progressive work intensity (i.e., to the muscle lactate threshold) than the LAT-4mM (11).

Since it has been confirmed that creatine administration results in an increase in the total intramuscular Cr, as well as Pcr content (2, 10, 18), it seems likely that the
improved ability to perform the supramaximal exercise after creatine loading depends mostly on an increase in PCr. The beneficial effect of creatine ingestion on sprint performance has been reported by some authors (2, 8, 38), although this effect has not been consistently shown by others (6, 12, 15, 24, 26). The very variable test protocols used in the cited reports (i.e., single or repeated, very intensive or maximal exercise bouts with different break durations) may be responsible for these conflicting findings. The present results indicating marked prolongation of the rowing time with the maximal power output till exhaustion after creatine supplementation are in agreement with the data obtained by Bosco et al. (5), who used a comparable experimental procedure (all-out treadmill running). During the recovery period following the supramaximal exercise test, creatine supplementation had no significant effect on blood LA concentration, which confirms the findings of Birch et al. (4) and Odland et al. (26).

Although the positive ergogenic action exerted by creatine appears to be widely accepted, the mechanism of this influence is still unclear. It can be suggested that creatine ingestion enhances the ability to perform strenuous exercise by increasing the initial amount of Cr and PCr content in the muscle cells and accelerating the rate of PCr and ATP resynthesis, since the decreased phosphocreatine availability in the working muscles impairs exercise performance (17, 19, 21). The ability to maintain a high rate of anaerobic ATP production from phosphocreatine hydrolysis after Cr supplementation might be expected to delay fatigue, especially during high-intensity intermittent exercise, as a consequence of increased PCr availability in the type II muscle fibers (8, 9), and lowered accumulation of plasma ammonia (4). Reduction of muscle PCr utilization and Pi accumulation, as well as a decrement of the muscle pH, found by Rico-Sanz (27) during low-intensity exercise after creatine loading, indicates that the fatigue delaying effect of Cr ingestion may occur also during prolonged endurance work. It should be noted that after Cr treatment, the resting PCr content was also shown to rise in the type I muscle fibers (8). The decreased blood LA accumulation, found in this study during submaximal exercise loads, indirectly supports the Casey et al. finding (8). Results of the electromyographic measurements reported by Stout et al. (34), who evaluated physical working capacity at the vastus lateralis muscle fatigue threshold, confirmed the suggestion that Cr loading may delay the onset of neuromuscular fatigue during exercise.

Summarizing, the present work demonstrated that oral creatine supplementation for a few days may improve endurance and anaerobic performance in elite athletes, independent of the effect of intensive endurance training itself. Thus, the creatine loading in highly trained top athletes, widely applied in sports practice, may be recommended as justified.

References


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