Effects of oral creatine supplementation on performance and muscle metabolism during maximal exercise

by

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ABSTRACT

The purpose of this study was to determine the effects of oral creatine supplementation on performance and muscle metabolism during maximal exercise. Nine subjects (5 female, 4 male) performed two 30 s maximal exercise bouts on a cycle ergometer separated by a period of two weeks to allow for adequate washout. Each exercise bout was preceded by 4 days of supplementation with a placebo (PL) or creatine (CR). The subjects consumed 5g of PL or CR four times a day prior to the trial. Treatments were administered in a double-blind, cross-over design. Power output was measured in watts every second for 30 s. There were no significant differences in average power output, peak power, or percent decline from peak power. There were no significant differences in muscle or plasma lactate concentrations. Total muscle Cr concentration was significantly higher in CR (20.0 $\pm$ 0.9 vs.. 15.8 $\pm$ 2.0 mmol/kg; $p<0.05$) prior to exercise and immediately following exercise (20.7 $\pm$ 0.9 vs. 14.8 $\pm$ 1.7 mmol/kg; $p<0.05$). There was no significant difference in muscle creatine phosphate concentration; however, the change in muscle PCr concentration tended to be greater during CR (6.4 $\pm$ 1.3 vs. 2.5 $\pm$ 1.6 mmol/kg; $p = 0.07$). The results indicate that four days of oral creatine supplementation does not improve power output on a single maximal cycle ergometer exercise, but may affect energy use in muscle metabolism.

INTRODUCTION

Creatine is a substance found in muscle that combines with phosphate to form creatine phosphate. Creatine phosphate reacts with adenosine di-phosphate to regenerate adenosine tri-phosphate in working muscle. Dietary supplementation of creatine may increase the total creatine and creatine phosphate content of the muscle (12, 17). Karvonen et al. (27) found that muscle creatine phosphate levels drop significantly after the performance of a 300 meter run, which lasts 30 to 40 s suggesting that the lack of creatine phosphate may somehow limit performance during intense, short term exercise.

Greenhaff et al. (12) found that subjects who supplemented their diet with creatine were able to sustain a higher peak torque during the latter portion of repeated isokinetic leg contractions compared with subjects ingesting a placebo. The results of these studies indicate that creatine supplementation may enhance performance in the athletic arena.

There has been little research on the effects of creatine supplementation on performance. To date, there have been no studies that measured continuous power output during a short term maximal exercise. Therefore, the purpose of this investigation was to determine whether creatine supplementation improves power output and to examine the effects on muscle metabolism during a 30 s maximal exercise bout on a cycle ergometer in college age subjects.

REVIEW OF LITERATURE

Muscular contractions require a continuous supply of energy. As the intensity of the exercise increases so does the demand for energy. The source of this energy is adenosine tri-phosphate (ATP). The human body has several sources for providing ATP used by working muscles.

The system providing most of the energy for short term (~0-30 s) intense (>100% VO_2 max) exercise is the adenosine tri-phosphate - phospho-creatine (ATP-PCr), or phosphagen system. It is this energy system that is thought to be the primary mechanism by which ATP is synthesized during bouts of exercise lasting from 0-30 s.

Current research suggests that the ATP-PCr system may be enhanced through the ingestion of supplemental creatine (17). This review will examine the function of the phosphagen system, influence of exercise and training on this system, and the impact of creatine ingestion on performance and the muscular content of creatine.

The phosphagen systems and exercise

Human muscle stores very little ATP (37). Since this supply is exhausted very quickly during exercise, the body must continuously regenerate ATP. The ATP-PCr system quickly rephosphorylates the adenosine di-phosphate (ADP) formed from the breakdown of ATP. Muscle is able to accomplish this regeneration because it stores a great deal more PCr than ATP. However, the supply of PCr in muscle is also exhaustible.

Several studies have documented significant depletion of PCr stores during short term intense exercise (8, 20, 21, 24, 26, 27). The capacity for the system to supply energy during exercise ranges from 15 s to 2 min. Most studies suggest, however, that maximal PCr depletion occurs within two min after the onset of exercise, and that most of the depletion occurs within 30 s (20, 24, 26). The level of depletion, which depends on the intensity of the exercise, usually ranges between 50 and 80% of total stores (24, 27, 37). After two min of exercise, no further depletion occurs, even when exercise is continued, suggesting that other energy sources are supplying ATP (26).

The reactions of the phosphagen system

When ADP accumulates in the muscle, creatine kinase is activated. This enzyme catalyzes the reaction in which PCr breakdown is coupled to the phosphorylation of ADP (37). This reaction continues to proceed as long as the ADP/ATP ratio is high and PCr levels in the muscle are sufficient to maintain ATP regeneration (6). The mechanism is shown by the following reaction:

$$ADP + PCr + H^{+} \xleftrightarrow{\text{Creatine kinase}} Cr + ATP$$

When exercise ceases, the remaining creatine in the muscle is rephosphorylated. This reaction requires ATP, and is inhibited if blood flow is occluded (21).

A related energy system that provides ATP for short term exercise is the purine nucleotide cycle (PNC) (28, 39). Adenosine monophosphate (AMP), produced when two molecules

of ADP combine with water in the presence of adenylate kinase to form ATP, begins the cycle (Figure 1). This reaction helps regenerate ATP but has some negative consequences.

Adenosine monophosphate enters the purine nucleotide cycle and forms inosine monophosphate (IMP) and ammonia. Inosine monophosphate combines with aspartate and GTP to form adenylosuccinate and GDP. Adenylosuccinate forms AMP and the Kreb's cycle intermediate fumarate. The AMP is useful in helping regulate metabolism, and fumarate provides material that will eventually form oxaloacetate and combine with acetyl CoA in the operation of the Kreb's cycle. Although ammonia is a stimulator of phosphofructokinase, an accumulation of ammonia can be toxic (6). If the ammonia is not removed by the liver, it can cause subnormal temperature, weak pulse, gastroenteric symptoms, and possibly cause hepatic coma (22).

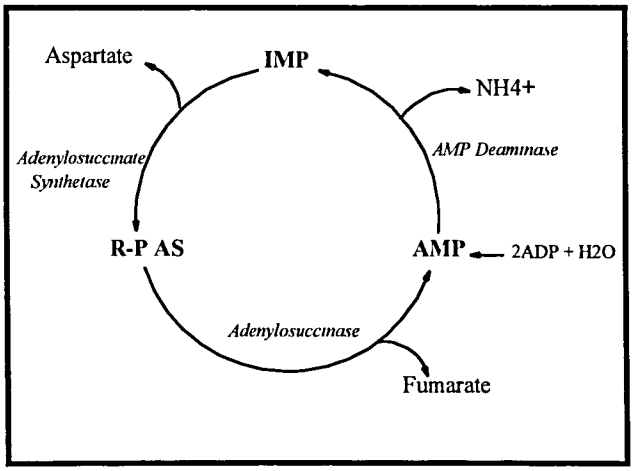

Figure 1. Purine nucleotide cycle

R-P-AS : ribose 5 adenylosuccinate.
IMP inosine monophosphate
AMP adenine monophosphate

PCr use and recovery

Hitchcock (21) determined that muscle PCr concentration decreased in proportion to the intensity of the exercise performed. After two min of recovery, 75-90% of the PCr in the muscle was restored. It appears that pH may have an effect on the recovery of PCr, because when pH is low, the restoration of PCr is inhibited. The low pH level inhibits creatine kinase. Recovery of short term power after exercise also appears to be coupled to the resynthesis of PCr.

Since the breakdown of PCr to creatine and phosphate consumes a hydrogen ion, creatine is also a buffer of hydrogen ions (6, 19). This reaction accounts for a significant portion of the theoretical buffering capacity of hydrogen ions in exercising muscle (35). The accumulation of hydrogen ions has been proposed as a possible cause of muscle fatigue (26). Increasing the creatine level in the muscle will increase the buffering capacity if the extra PCr is hydrolyzed, and may delay the onset of muscle fatigue.

Hirvonen et al. (20) studied PCr depletion during intense exercise. These authors determined decreases in running speed begin when high energy phosphate stores are depleted. As a result, energy must be supplied by other systems, primarily glycolysis. In this study, 88% of the PCr that was to be depleted was broken down within 5.5 s. The sprinters who could attain a higher maximal speed used almost 100% of their PCr stores in this same time. It was proposed that the running speed decreased because ATP rephosphorylation was reduced once the PCr stores were depleted. Hirvonen et al. proposed that the runners who are faster may be so because of their ability to utilize the PCr stores at a faster rate, producing more power in a short time.

Spriet et al. (36) studied electrically stimulated muscle contractions lasting 102 s. During this exercise, PCr provided 40% of the ATP produced for these contractions. When the PCr stores were depleted, the ATP turnover decreased 55-60%, while force production also decreased dramatically. The results of these studies suggest PCr is the major component supplying energy during short term, dynamic exercise.

PCr and fiber type

Tesch et al. (38) found that fast twitch fibers store 13% more PCr than do slow twitch fibers. These authors also determined PCr depletion is greater in fast twitch fibers after 30 maximal leg contractions. However, during the first min of recovery, PCr was resynthesized in slow twitch muscle faster than it is in fast twitch fibers. These findings are not surprising when the nature of the exercise is considered. Fast twitch fibers are recruited to perform maximal leg contractions, and the ATP-PCr system supplies most of the energy for the exercise. Slow twitch fibers have greater vascularization than fast twitch fibers, resulting in a greater blood supply to the slow twitch fibers. Since the resynthesis of PCr requires an adequate blood supply, the slow twitch fibers are better adapted to resynthesize PCr.

Training and PCr

The effect of training on PCr concentration in skeletal muscle has not been well documented. Some researchers suggest that the PCr concentration in muscle is increased by endurance training (4, 11, 40). Other findings suggest that the PCr level may be enhanced by sprint training (10, 35) or find no change in muscle creatine concentration with sprint training (17). Furthermore, sprint training induces hypertrophy, which should cause an increased

total creatine concentration of muscle. These conflicting findings suggest that more research is needed before a determination can be made on the effect of training on muscle creatine concentration.

Creatine supplementation

Creatine supplementation is not needed for humans to maintain adequate stores. The majority of creatine in the body is found in skeletal muscle. Creatine stores are maintained by consumption of a normal, mixed diet. Red meat is very high in creatine content. Creatine can also be synthesized in the body from the amino acids arginine and glycine (34). Creatine is water soluble, and can be easily transported into muscle tissue from the blood.

Effects on muscle creatine level

There is little information on creatine ingestion and its influence on exercise. Two studies in the early part of the 1900's on a limited number of subjects had conflicting findings as to whether creatine supplementation increases muscular content of creatine (7, 29). These studies did not use a muscle biopsy to determine the creatine concentration of muscle. Instead, muscle PCr concentration was estimated with creatine balance calculations.

More recently, studies were conducted that directly measured the muscular content of creatine. Harris et al. (17) studied the effects of oral creatine supplementation on total muscle creatine and creatine phosphate content in 17 subjects. The authors determined that 5 g of creatine was sufficient to raise the plasma creatine to an acceptable level for absorption into the muscle. After supplementing the subjects with 5 g of creatine four to six times a day

for 4-5 days, the creatine content of the muscle was increased from 126.8 mmol/kg dry muscle (DM) to 148.6 mmol/kg DM. The study also determined that creatine uptake into the muscle was greatest during the first two days of supplementation. In addition, subjects who had a low muscle creatine level to begin with were able to increase their PCr level substantially more than subjects who had normal levels of creatine in the muscle.

Effects on performance

Harris et al. (17) also determined that subjects who performed one hour of hard exercise each day with one leg were able to raise their muscle creatine level higher in the exercised leg than the non-exercised leg. In these subjects, the mean creatine content in the muscle of the control (non-exercised) leg increased from 118 mmol/kg DM to 148 mmol/kg DM. The mean creatine content in the exercised leg increased to 162 mmol/kg DM.

In a follow up study by Greenhaff et al. (12), the impact of creatine supplementation on torque production during isokinetic leg exercise was studied. One group received a 5 g oral creatine supplement four times a day for five days, while another group served as a control. Each group performed 5 bouts of 30 maximal isokinetic leg contractions. The group that received the supplement was able to increase their total torque production in three of the five exercise bouts by an average of 131, 102, and 84 Nm. After Cr ingestion, peak torque was greater during the final 10 contractions in exercise bout 1, and during contractions 11-20 in the exercise bout 5.

Creatine supplementation appears to speed up resynthesis of PCr after intense electrically simulated isometric contraction. Greenhaff et al. (13) observed that when muscular PCr level was raised by creatine supplementation, PCr resynthesis increased by 42% during the

second min of recovery. Enhanced resynthesis of PCr was not seen in subjects who did not have an increased muscle PCr concentration following supplementation.

Balsom et al. (2) studied the effects of creatine supplementation on six repeated bouts of 6 s maximal bicycle sprints with 30 s of passive rest. The results indicate that creatine supplementation enhanced performance in the supplemented group in the 4th, 5th and 6th bouts of exercise. Improved performance in the last three sprints suggest enhanced resynthesis of PCr was a factor in the supplemented group.

Preliminary results from several studies involving creatine supplementation indicate that supplementation enhances short term anaerobic capacity (25, 14), and also enhances performance during repeated bouts of maximal muscle contractions (31, 16). Supplementation does not appear to improve performance in intermediate length (~80-100s) exercise (34).

Cooke et al. (9) examined the effects of creatine supplementation on a single 15 s maximal bicycle ergometer sprint. The authors' conclusion was that oral creatine supplementation for 5 days does not result in improved power output or reduced fatigue in continuous high intensity exercise.

Creatine supplementation does not appear to influence exercise lasting several min. Balsom et al. (2) determined that creatine supplementation, performed similarly to the methods of Harris and Greenhaff (12), did not improve performance in a 3 to 6 min run to exhaustion.

The mixed results of previous studies on oral creatine supplementation indicate that performance during short term exercise may be enhanced, but not during a single bout of exercise. Although Greenhaff (12) and Balsom (2) both observed an increase in

performance, this increase was not significant until the later stages of repeated bouts of exercise. These results suggest enhanced resynthesis of PCr during the rest interval, resulting in an increase in performance in the later bouts of exercise.

In the studies by Greenhaff (12), Cooke (9) and Balsom (2), muscle biopsies were not taken. Since the creatine concentration in muscle was not measured, the studies assume that the administration of oral creatine supplement raised the concentration of creatine in the muscle. Greenhaff et al. (12) incorporated student's paired t-test for data analysis, which may have resulted in type I errors. Finally, none of the studies monitored the subjects' diet, which could also influence on the creatine content of muscle.

The combination of the results from the current research suggest that creatine supplementation may enhance the performance of short term, dynamic exercise. It is therefore the purpose of this study to examine the effects of oral creatine supplementation on performance and muscle metabolism during a 30 s maximal exercise on a cycle ergometer.

METHODS

Subjects and general design

Five female and four male subjects ranging in age from 20 to 28 years completed the study. Subject characteristics are summarized in Table 1.

Subjects reported to the laboratory on two separate occasions to be tested. One treatment consisted of consuming 5 g of creatine monohydrate four times a day, for the four days prior to exercise (CR). The other treatment consisted of consuming 5 g of glucose four times a day for the four days prior to exercise (PL). Both creatine and placebo were administered using 6 gelatin capsules containing 5 g of the substance. Each treatment was separated by 2 weeks. Subjects were instructed to maintain a constant level of physical activity between trials.

Table 1. Subject characteristics

Characteristic	Male	Female
Age (years)	20 ± 1	23 ± 0
Height (cm)	176.5 ± 3.4	165.1 ± 3.5
Weight (kg)	71.2 ± 4.4	59.9 ± 4.4
Body fat (%)	9.4 ± 1.0	20.4 ± 3.2
VO_2 peak (ml/kgxmin)	45.6 ± 2.2	34.9 ± 3.3

Values are ± SEM, n = 9.

Pilot study

A pilot study was conducted on two subjects to determine the washout time after creatine supplementation. Subjects ingested 5 g of creatine four times a day for four days. Muscle biopsies were taken prior to supplementation, and 1, 3, 6 and 8 days after supplementation ceased.

In these two subjects, creatine supplementation nearly doubled the muscle Cr concentration (Table 2). Following cessation of creatine supplementation, the muscle Cr concentration returned to control values within three days.

Table 2. Total creatine concentration of muscle during the pilot study.

Day	Mean total Cr (mmol/kg)
pre-supplementation	24.7
1	43.2
3	17.4
6	23.4
8	27.9

Preliminary testing

Subjects reported to the laboratory three times prior to the experiment to be familiarized with the procedure and equipment to be used. The subjects were asked to perform a maximal

30 s ride during each visit to familiarize them with the test protocol and prevent learning effect during the trials. Body fat percentage was determined by using a summation of skin fold thickness measurement technique (23).

Peak oxygen uptake ($V0_2$ peak) was determined during exercise on an electronically braked cycle ergometer (Lode Excalibur, Cal Med, Brea, CA). Subjects began exercising at a load of 50 watts at 70 rpm. The power output was increased by 50 watts every two min until voluntary exhaustion. Expired gases were directed through a three-liter mixing chamber and analyzed for oxygen (Applied Electrochemistry SA-2 Oxygen Analyzer) and carbon dioxide (Beckman LM-1 CO_2 Analyzer) fractions. The gas analyzers were calibrated with a known standard prior to each trial. Analog inputs from these instruments were interfaced with a DOS based computer for calculation of VO_2 and respiratory exchange ratio (RER) (Turbofit, Vacumed, Ventura, CA).

Exercise test

The exercise test consisted of a thirty second maximal performance on an electronically braked cycle ergometer (Lode Excalibur, Cal Med, Brea, CA) with warm-up. No encouragement was given. Performance was assessed as the mean power output produced over the thirty second time period. The cycle ergometer was interfaced with a DOS based computer to sample power output three times each second. The subjects started exercise at 0 rpm, and the ergometer was programmed to measure power output based on how fast the subject could pedal. Resistance was set to limit the cadence to approximately 120 rpm.

Biochemical analysis

A two inch polyethylene catheter was inserted into a forearm vein for collection of blood samples. Blood was drawn prior to the exercise period, immediately following the exercise bout, and one, three, five, seven, ten, and fifteen min post exercise. Blood samples were kept on ice until centrifugation. Lactate concentrations were determined on plasma samples with an automated analyzer (YSI 2300 GL Stat, Yellow Springs Instruments, Yellow Springs, Ohio).

Muscle biopsies were taken from the vastus lateralis prior to the exercise and immediately (~ 5 s) post exercise. The biopsies were obtained as described by Bergstrom, and quick frozen in liquid nitrogen within three seconds (5). The biopsies were analyzed for creatine phosphate and total creatine concentration as described by Harris et al. (18). Muscle lactate concentration was determined fluorometrically (32).

Dietary control

In an attempt to standardize the blood creatine concentration, subjects kept a 4 day dietary record for both treatment periods of the experiment, and reproduced their diets as closely as possible during both treatment periods. Dietary compliance was verified by nutrient analysis of food consumption data record (Food Comp, Iowa State University, Ames, IA).

Calculations and statistics

Muscle PCr, muscle lactate, plasma lactate, and power output were analyzed using two way analyses of variance (ANOVA) for repeated measures. Where appropriate, significant mean differences were located using the Newman-Keuls multiple comparison test. All data are expressed as means $\pm$ SE.

RESULTS

Dietary record

Nutrient analysis of four day diet records indicated an estimated total intake of 7443 kJ/day (Table 3). Carbohydrate consumption averaged 233 gm (~60 % of total kJ), protein consumption averaged 69 g (~16 % of total kJ), and fat consumption averaged 52 g (~ 24% of total kJ).

Table 3. Dietary intake

Substrate	Day 1	Day 2	Day 3	Day 4
Calories (kJ)	6798 ± 883	7610 ± 716	8179 ± 1063	7187 ± 527
Carbohydrate (g)	215 ± 76	227 ± 48	296 ± 81	196 ± 33
Protein (g)	64 ± 9	62 ± 9	88 ± 14	63 ± 9
Fat (g)	45 ± 11	48 ± 7	54 ± 11	45 ± 6

Values are ± SEM, n = 9.

Power output

Power output (Figure 2) was calculated for each five second time period. There were no significant differences between CR and PL for any of the time periods. Power output for CR was greatest in the time interval from 5-10 s (509 ± 94 watts). Power output for PL was greatest in the time interval from 10-15 s (553 ± 69 watts). The time to reach peak power output ranged from 7 s to 13 s for both CR and PL, while mean time to peak power was 9 s

for both trials. Mean power output over the 30 s exercise bout was similar for PL (458 ± 12 watts) and CR (461 ± 12 watts). These means were not significantly different from the mean power output for the third practice trial (458 ± 12 watts). Peak power output was similar in CR (627 ± 70 watts) and PL (624 ± 76 watts). Nadir power (CR: 349 ± 30 watts; PL: 344 ± 29 watts) and percent decline in power (CR: 77 ± 8%; PL: 78 ± 9%) were not affected by dietary creatine supplementation CR.

Muscle creatine level

Total Creatine

Resting muscle total creatine concentration (Figure 3) was higher in CR (20.0 ± 0.9 mmol/kg) compared with PL (15.8 ± 2.0 mmol/kg) ($p < 0.05$). Following exercise, muscle total creatine concentration was also higher in CR (20.7 ± 1.2 mmol/kg) compared with PL (14.8 ± 1.7 mmol/kg) ($p < 0.05$).

Creatine phosphate

Muscle creatine phosphate concentration (Figure 4) was not significantly different prior to or immediately following exercise in CR compared to PL. Although resting muscle creatine phosphate concentration tended to be greater in CR (9.9 ± 1.1 mmol/kg) than PL (5.8 ± 2.2 mmol/kg), the difference was not statistically significant. After exercise, muscle creatine phosphate concentration tended to be greater in PL (5.0 ± 1.4 mmol/kg) compared with CR (3.5 ± 1.2 mmol/kg). The change in PCr during exercise (Fig. 5) tended to be

greater in CR (6.4 $\pm$ 1.3 mmol/kg) compared with PL (2.5 $\pm$ 1.6 mmol/kg) ($p = 0.07$ by one-tailed t-test).

Muscle lactate

Muscle lactate concentration (Figure 6) was not significantly different prior to or immediately following exercise in CR compared to PL. Muscle lactate rose from 2.0 $\pm$ 0.7 mmol/kg pre exercise to 17.4 $\pm$ 2 mmol/kg post exercise in CR compared to 5.0 $\pm$ 0.9 mmol/kg pre exercise and 13.5 $\pm$ 2.5 mmol/kg post exercise in PL.

Plasma lactate

Plasma lactate concentration (Figure 7) was not significantly different at any time point when comparing CR and PL. During CR, plasma lactate concentration rose to a maximal value of 13.5 $\pm$ 0.6 mmol/L ten min post exercise. In PL, plasma lactate concentration rose to a maximum value of 13.0 $\pm$ 1.1 mmol/L five min post exercise.

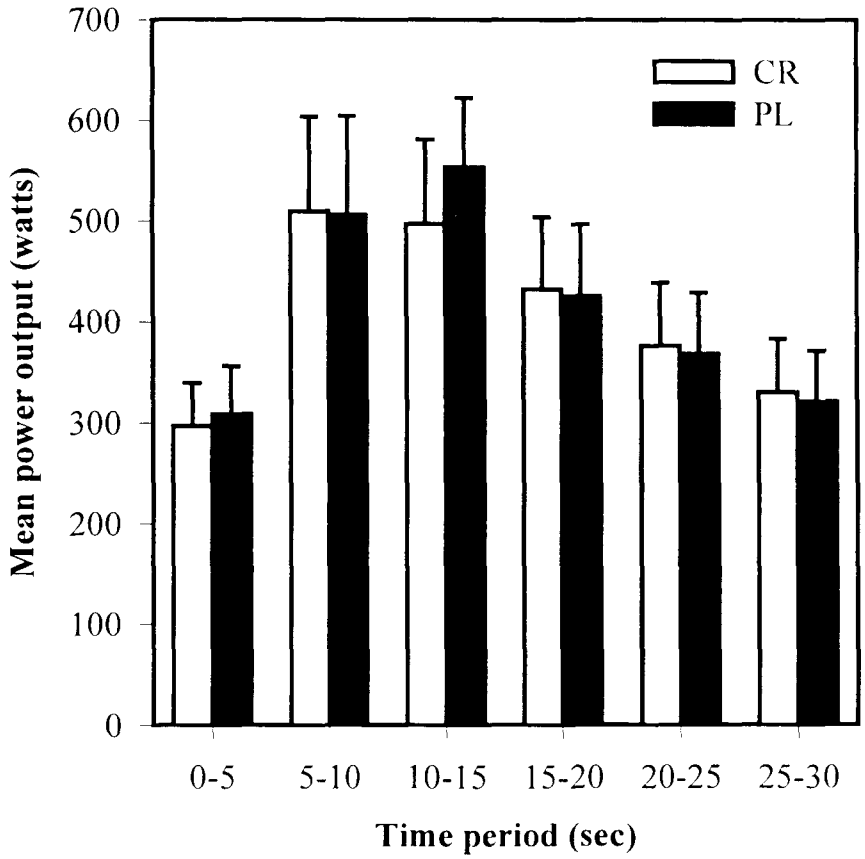

Figure 2. Mean power output at 5 s intervals during a 30 s maximal exercise after 4 days of placebo (PL) or creatine (CR) supplementation.

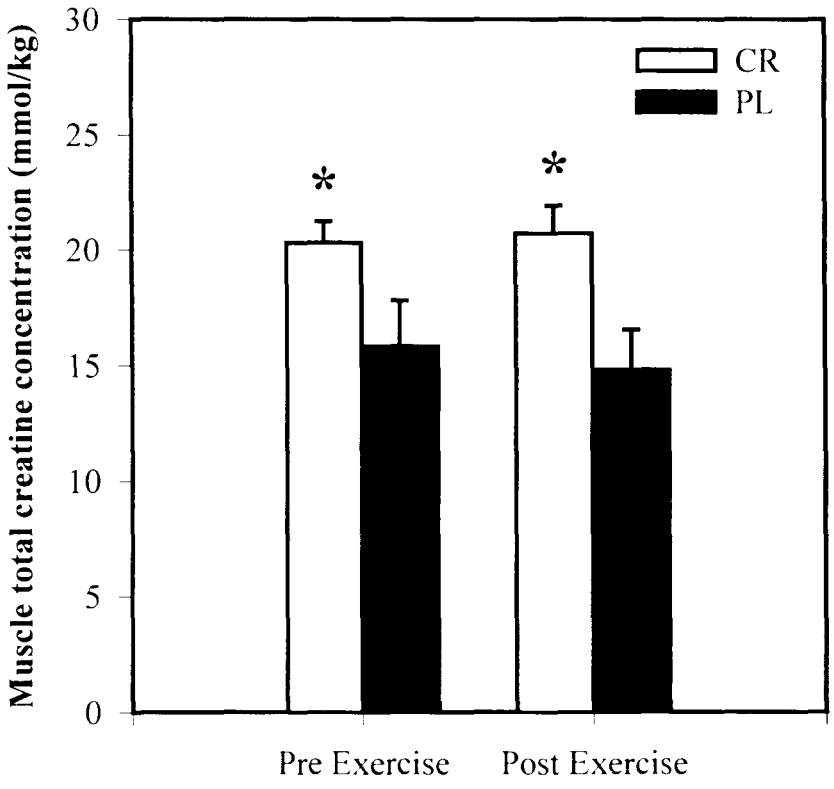

Figure 3. Total creatine concentration in muscle measured at rest and following 30 s of maximal exercise.

*** CR significantly different from PL ($p < 0.05$)**

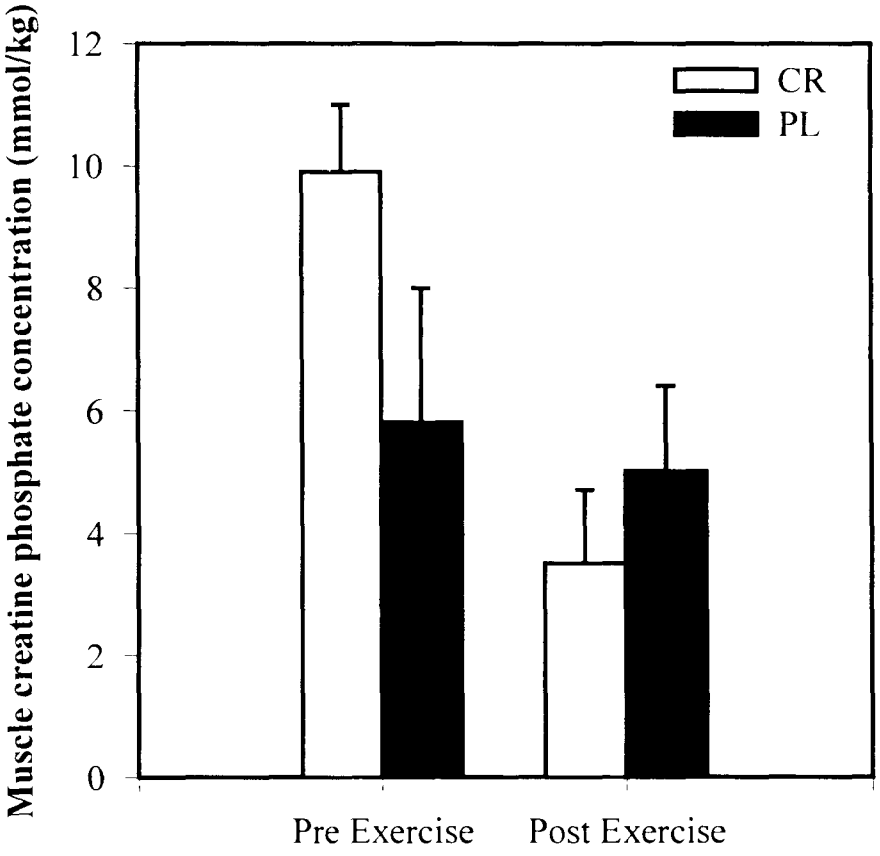

Figure 4. Creatine phosphate concentration in muscle measured at rest and following 30 s of maximal exercise.

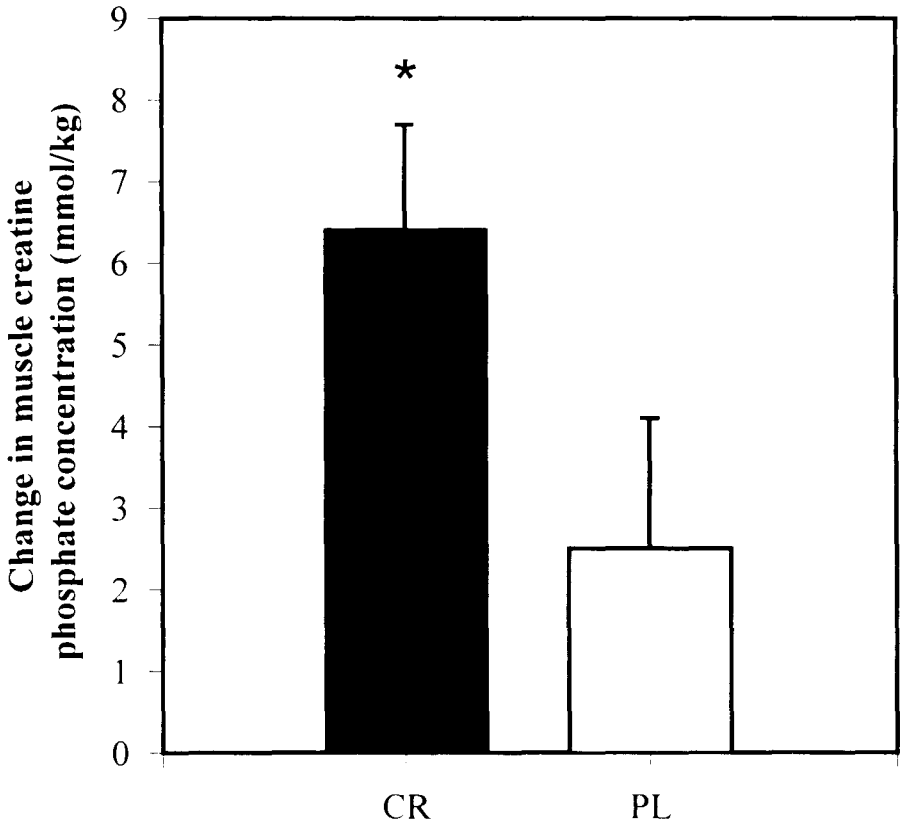

Figure 5. Change in creatine phosphate concentration of the muscle during exercise.

*** CR vs. PL; p = 0.07**

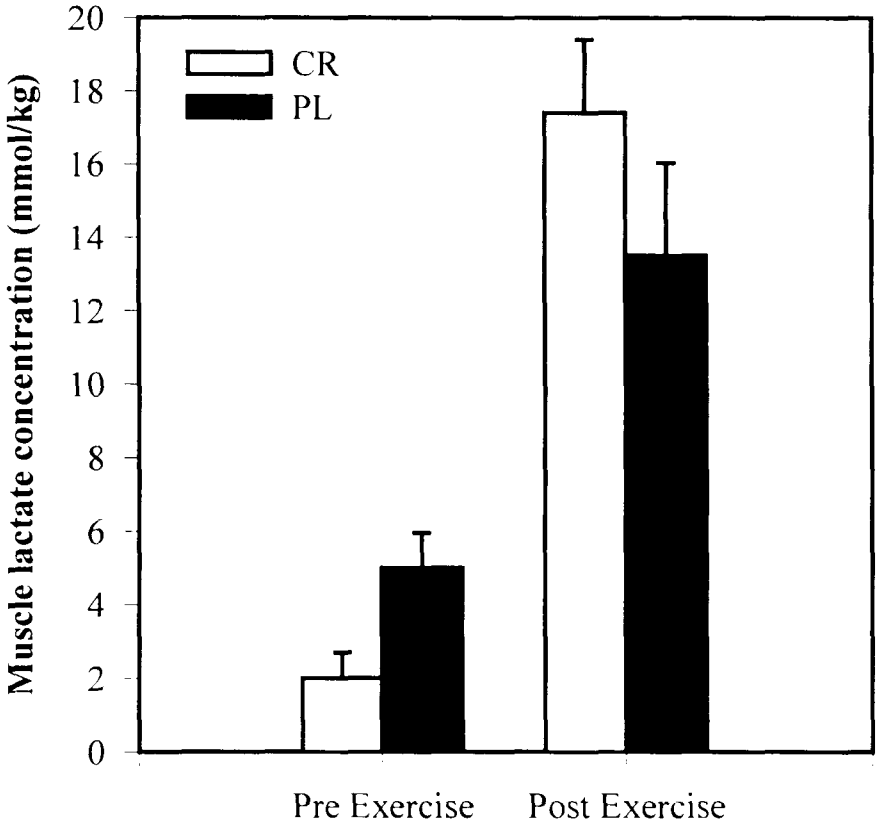

Figure 6. Muscle lactate concentration measured at rest and following 30 s of maximal exercise.

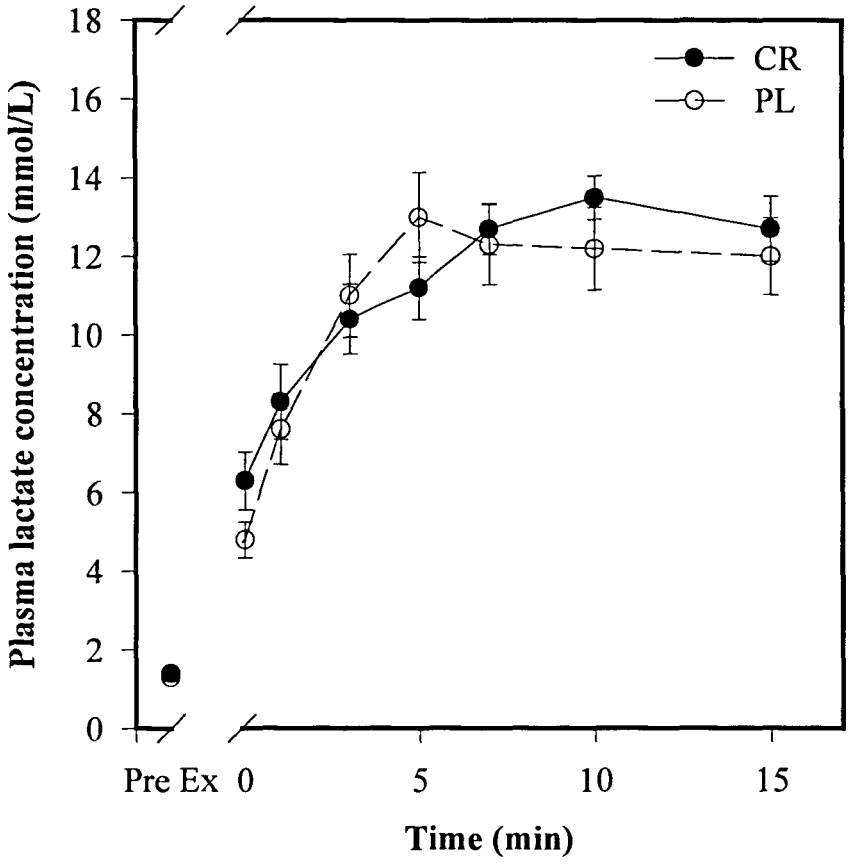

Figure 7. Plasma lactate concentration measured at rest, immediately following and 1, 3, 5, 7, 10 and 15 min into recovery.

DISCUSSION

The main finding of this study is that four days of oral creatine supplementation did not improve the mean power output of a 30 s maximal cycle ergometer exercise. Although total creatine concentration in the muscle was elevated, creatine phosphate concentration was not elevated significantly as described in previous research (17). The amount of creatine phosphate used during exercise tended to be greater in CR compared to PL. The results of this study agree with Harris et al. (17) that four days of creatine supplementation significantly increases the total creatine concentration in the muscle.

Total creatine and PCr concentrations measured in the muscle were lower in some subjects by as much as one third compared to other studies (17, 18). These lower values, and lack of statistical significance may be related in part to sampling errors, and to the small size of many of the muscle samples obtained (< 30 mg), especially those obtained following exercise. The inaccuracy of dissection and weighing small samples of muscle tissue contributed to the error of measurement.

The finding that PCr use was increased in CR, but did not lead to an increase in power output is puzzling. One possible explanation is that the increased use of PCr during exercise was not sufficient to produce a significant difference in power output on the ergometer. Creatine phosphate has an energy content of 44 kJ/mole (1). The subjects in this study had an increase in PCr use of 3.9 mmol/kg. Assuming an average muscle mass in the legs to be 14 kg, 54.6 more mmol of PCr would be available in CR. This would result in a 2.4 kJ increase in energy production if all of the PCr was utilized. One watt is equal to 1 Joule/sec.

Assuming 29% efficiency during cycling (6) the expected increase in mean power output would be 24 watts. This small increase in power output may not be of a sufficient magnitude to be measurable by our instrumentation.

The similarity of response in plasma and muscle lactate in both PL and CR indicate that glycolysis was a significant energy contributor during the exercise performance. As the concentration of muscle PCr increases, one would expect a lower plasma lactate concentrations if power output remained the same. Greenhaff et al. (12) observed a similar response in plasma lactate concentrations, yet found a better maintained torque production of leg contractions. The increase in power was attributed to increased (but unmeasured) PCr concentration in the muscle, and therefore more use of PCr during exercise. This finding contrasts with the results of this study which showed increased PCr use, a similar lactate response, and no change in power output during exercise.

The results of this study agree with the results of Cooke et al. (9) that creatine supplementation does not increase performance in short term maximal exercise. The results do suggest a shift of energy use within the muscle. In CR, more PCr was utilized without any significant change in blood lactate accumulation. These finding suggest that glycolytic flux was similar in both trials. This result may indicate a higher reliance on the purine nucleotide cycle in PL. Since both trials resulted in similar power outputs, it is likely that ADP would be produced at the same rate. In PL, ADP would react to form ATP and AMP. The AMP enters the PNC and forms IMP, which leads to the deamination of aspartate to fumarate, and the formation of ammonia. Increased use of the PNC may result in an increased accumulation of plasma ammonia, which was not measured in this study. Consistent with this

hypothesis, Greenhaff et al. (12) measured plasma ammonia, and found it to be significantly lower following creatine supplementation during the final two bouts of exercise.

Greenhaff et al. (13) suggested that elevated Cr level after supplementation can contribute to enhanced PCr resynthesis due to the increased free Cr availablility. Although repeated bouts were not analyzed in this study, it is possible that the increased Cr concentration may have enhanced performance on a second or third bout of exercise.

There was no difference in the decline in power output during exercise. This effect was demonstrated in a previous study (9). Although muscular PCr concentration was not elevated significantly in this study, more PCr was used in CR. Elevation of PCr concentration may delay the decline in power output in a maximal exercise performance by delaying the onset of glycolysis, and by slowing the accumulation of ADP. Delaying glycolysis may allow a greater contribution by this energy system later in the exercise, and help maintain power output in the latter phase.

Creatine supplementation may also improve performance during more prolonged sprint exercise by improving acid-base balance. Hydrogen ion accumulation has been suggested as a possible cause of muscle fatigue (26). Since PCr hydrolysis consumes a hydrogen ion, muscular hydrogen ion accumulation may also be attenuated, possibly delaying fatigue.

Subjects participating in this study were in average physical condition. It has been demonstrated that sprint training enhances creatine utilization (2). In addition, sprint training increases the size of FT fibers, which contain more CP than do slow twitch fibers (38). If the subjects in this study had been highly trained, it is possible that the creatine supplementation may have produced different results.

The washout time following creatine supplementation has not been previously reported. In the two subjects participating in the pilot study, the increase in total muscle creatine concentration was similar to Harris et al. (17). After one week, resting muscle creatine concentration returned to baseline levels in both subjects. Therefore, the two weeks allowed between trials in this study was sufficient to allow muscle creatine concentration to return to normal.

The potential health risks of ingesting large amounts of creatine over a period of time have not been examined. An increase in mean body weight after four days has been demonstrated (13). Supplementation of 5 g of creatine corresponds to the amount contained in 1.1 kg of fresh, uncooked steak (17). The recommended supplementation ranges from 15-25 g a day. There is no recommendation given on products sold as to the length of the supplementation period. Although a significant portion of this creatine is undoubtedly lost through urinary excretion, it is currently unknown what system might be affected. Since creatine is widely available, potential health risks should be examined.

Creatine supplementation in small amounts has been used as treatment for atrophy of the choroid and retina. Subjects undergoing this treatment take 0.5 g of creatine three times a day for long periods of time (> 1year). The only side effect noted was a slight weight gain at the beginning of the treatment (41).

In conclusion, the results of this investigation demonstrate that oral creatine supplementation, while increasing total creatine concentration in the muscle, does not enhance performance of a single thirty second maximal exercise. Further research on creatine ingestion should be conducted before it is recommended as an ergogenic aid to short term performance.

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