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Effects of creatine supplementation on power output during repeated bouts of supramaximal cycling

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EFFECTS OF CREATINE SUPPLEMENTATION ON POWER OUTPUT DURING REPEATED BOUTS OF SUPRAMAXIMAL CYCLING

by

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An Abstract

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ABSTRACT

This study examined the effect of creatine supplementation on power output during repeated bouts of high intensity cycling. Using a double blind protocol, 14 trained male cyclists were randomly divided into placebo (P) and creatine (Cr) groups. They completed five tests on a mechanically braked cycle ergometer, each separated by at least 48 hours of rest. The tests included a Wingate anaerobic power test, a maximum oxygen consumption (VO_2 max) test, and three recovery tests. The recovery tests consisted of four, 45-second maximal intervals separated by 45 seconds, 90 seconds, or 135 seconds of active recovery. Creatine subjects ingested 25 g of creatine per day for 5 days and 5 g per day thereafter until testing was completed; P consumed a similar quantity of a placebo each day. The following measures were made during the recovery tests: mean and peak power, HR, VO_2, and blood lactate. Additionally, changes in percent fatigue, lean body mass (LBM), and creatinine excretion were calculated. Data were analyzed with a three-way repeated measures ANOVA for group X test X bout; a Tukey post-hoc HSD analysis was used to test for group differences when indicated. There were no significant differences in LBM, HR, VO_2, % fatigue, and peak and mean power output over time and between groups and recovery tests. In conclusion, creatine supplementation did not have any demonstrative effects on four, 45-second supramaximal cycling bouts with active recovery periods of 45 to 135 seconds.

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science thesis of

Brian J. Kelly

submitted in partial fulfillment of the requirements for the degree of Master of Science in Exercise and Sport Sciences at Ithaca College has been approved.

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Chapter 1

INTRODUCTION

Purpose of the Study

All levels of athletes seek the competitive edge. This may account for the widespread use of illegal drugs in sport, and the high sales figures for many nutritional supplements with purported ergogencity, such as creatine monohydrate, DHEA, and androstenedione (Maughan, 1995). Of the aforementioned supplements, creatine has been the most widely studied by scientists and consumed by athletes (Bosco, Tihanyi, Pupcspk, Kovacs, Gabossy, Pulvirenti, Tranquilli, Foti, Viru, & Viru, 1997; Brannon, Adams, Conniff, & Baldwin, 1997; Clark, 1997; Earnest, Almada, & Mitchell, 1997; Harris, Viru, Greenhaff, & Hultman, 1993; Kreider, Ferreira, Wilson, Grindstaff, Plis, Reinardy, Cantler, & Almada, 1997; Volek, Kraemer, Bush, Boetes, Incledon, Clark, & Lynch, 1997).

Data from many of the aforementioned studies show that creatine ingestion improves a person's ability to maintain power output during repeated bouts of high intensity exercise. This improved performance has been attributed to enhanced ATP resynthesis during recovery (Balsom, Harridge, Soderlund, Sjodin, & Ekblom, 1993, Balsom, Soderlund, Sjodin & Hultman, 1995; Earnest et al., 1997; Birch, Noble, & Greenhaff, 1994; Kreider et al., 1997). Based on these data, therefore, creatine supplementation may enhance performance in sports that require frequent bouts of high intensity exercise, such as road cycling (Maughan, 1995).

The ability of creatine supplementation to enhance cycling performance, for instance, is shown by studies that report improved power output during short, repeated bouts of high intensity cycling (Balsom et al., 1995; Balsom et al., 1993; Birch et al., 1994; Casey, Constantin-Teodosiu, Howell, Hultman, & Greenhaff, 1996; Dawson, Cutler, Moody, Lawrence, Goodman, & Randall, 1995; Earnest et al., 1997; Kreider et al., 1997). The extension of these findings to the competitive cycling arena, however, is limited by several factors. First, none of the subjects in the aforementioned studies were trained cyclists. Second, passive rather than active recovery was used in these studies; the opportunity for passive recovery rarely occurs during competitive road cycling. Another factor that limits the applicability of these studies to the competitive arena is the short duration of the cycling bouts, which lasted for less than 10 seconds in several studies (Balsom et al., 1993; Balsom et al., 1995; Kreider et al., 1997). In road racing, cyclists often perform several consecutive 30 to 60 second high intensity efforts such as during a series of attacks, or for the final sprint set-up. Thus, it remains to be seen if creatine supplementation benefits a trained cyclist in a more applied setting. The purpose of this study was to examine the effect of creatine supplementation on power output in trained cyclists during repeated bouts of relatively prolonged, high-intensity cycling.

Whereas the ability of creatine to increase power output during repeated bouts of high intensity exercise is well documented, there is little information on the minimum recovery time needed between work bouts to maintain power output. A work to rest ratio of 1:5 has been used in many studies (Balsom et al., 1993; Balsom et al., 1995; Birch et

al., 1994; Earnest et al., 1997; Kreider et al., 1997). A shorter work to rest ratio of 1:2 was used, however, by Greenhaff et al. (1993). They demonstrated that PCr resynthesis was increased by 42% during the second minute of recovery following creatine supplementation, a finding that suggests a shorter work to rest ratio may also enhance performance. Another purpose of this study, therefore, was to compare the effects of recovery time on power output during repeated bouts of high intensity exercise following creatine supplementation.

Scope of Problem

Fourteen male cyclists (18-40 y) served as subjects to test the effects of oral creatine monohydrate supplementation on recovery time during repeated bouts of high intensity cycling.

Problem Statement

The effects of creatine monohydrate supplementation on power output during repeated bouts of supramaximal cycling was studied in trained cyclists.

Hypothesis

1. Following creatine supplementation subjects will exhibit greater peak power output and less fatigue across repeated bouts of high intensity cycling compared to placebo subjects.
2. Creatine supplemented subjects will have greater resistance to fatigue during high-intensity exercise compared to placebo subjects.

cycling with a recovery period of 90-seconds, but not with recovery periods of 45 or 135 seconds.

Assumptions

The following assumptions applied to this study:

1. The subjects followed the supplement regimen as prescribed.
2. The subjects participated at their maximum ability during testing sessions.
3. The subjects followed pretesting instructions.
4. The subjects did not take other ergogenic aids during the study.
5. The subjects did not alter their training or dietary habits.

Definition of Terms

The following terms were operationally defined for the purpose of this study:

1. Repeated Bouts of Supra-maximal Cycling: Bouts of cycling using a predetermined load of 5.5% of body weight at which the subject was asked to give a maximal effort for a 45 second cycling period. The bouts were repeated four times, each interrupted by an active rest period.

2. Active Rest Period: A period of minimal activity between cycling bouts that ranged from 45 to 135 seconds during which the subjects maintained 70-80 rpms to recover from their maximal effort.

Delimitations

The delimitations of this study were as follows:

1. Only trained male cyclists between the ages of 18-40 y were tested, therefore these results may not be generalizable to other ages or females.

2. Creatine supplementation was generally less than 30 days, and therefore these results may not apply to those supplemented for longer periods of time.

Limitations

The limitations of the study were as follows:

1. Muscle biopsies were not taken from the subjects to determine baseline or post-supplementation muscle creatine levels.

2. Subjects were not tested on their own bicycles. This may have affected performance due to comfort level and/or psychological stress.

Chapter 2

REVIEW OF LITERATURE

Introduction

Creatine, or methylguanidine-acetic acid, is an amino acid that was first identified in 1832 by Chevreul (Balsom, Soderlund, & Ekblom, 1994; Zoeller & Angelopoulos, 1998). Creatine, which is mainly formed in the liver, is composed of three amino acids: arginine, methionine, and glycine. After synthesis, creatine is actively transported into many cells via a specific transport protein using the energy contained in the sodium gradient. This transport protein has a high affinity for creatine and concentrates it within the cell. Once in the cell, most creatine stays there, as the cell loses < 3% per day. The majority of creatine lost is excreted in the urine in the form of creatinine. Daily turnover of creatine to creatinine for a 70 kg male is approximately 2 g (Balsom et al., 1994).

In addition to the endogenous formation of creatine, the average daily diet supplies 1 g, mainly from the consumption of meat and fish (Englehardt, Neumann, Berbalk & Reuter, 1998). Collectively, the endogenous and exogenous sources of creatine sustain a plasma creatine concentration of 40 to 100 $u$mol L^{-1}; lower values of 25 to 32 $u$mol L^{-1} are sustained in vegetarians (Englehardt et al., 1998).

In humans, over 95% of total body creatine is in the skeletal muscle. Approximately one-third of this muscle creatine is in the free form, whereas the remaining amount is phosphorylated (PCr). Creatine levels in human skeletal muscle are

subject to individual variations including such factors as muscle fiber type, age, and disease (Balsom et al., 1994). Fast twitch or type II fibers, for example, have more creatine than slow twitch or type I fibers (Englehardt et al., 1998).

ATP Depletion

The energy needed to rephosphorylate ADP to ATP after exercise is supplied by muscle PCr in a 1:1 ratio: one molecule of PCr is needed to rephosphorylate one molecule of ADP. As PCr stores are depleted, performance deteriorates because of the inability to resynthesize ATP at the required rate. Brief bouts of high intensity exercise increase the ATP demand in the working muscles to several hundred-fold above resting values. In humans, for example, the rate of ATP turnover in dry muscle is approximately 6 $mmol \cdot kg^{-1} \cdot s^{-1}$ during 25 seconds of electrical stimulation of the quadriceps and between 13 and 15 $mmol \cdot kg^{-1} \cdot s^{-1}$ during 6 to 10 seconds of all out cycling. These data show that high intensity exercise can deplete PCr stores within 10 seconds based on normal total muscle creatine concentrations of 130 to 150 $mmol \cdot kg^{-1}$ of dry muscle (Balsom et al., 1994).

PCr Resynthesis

The resynthesis of PCr in human skeletal muscle is an oxygen dependent process composed of a fast and slow component (Haff & Potteiger, 1997). Following the completion of high intensity exercise, approximately half the PCr content is restored within one minute of recovery (fast component), and total creatine resynthesis is nearly complete after approximately five minutes (slow component) (Balsom et al., 1994). The

initial rate of resynthesis is fastest in type I fibers, which may be linked to their enhanced oxidative capacity. Increasing muscle creatine content may accelerate the rate of PCr resynthesis during high intensity, short duration exercise bouts (Kreider et al., 1997). For example, Greenhaff et al. (1994) found that creatine supplementation improved the rate of PCr resynthesis by approximately 42% during the second minute of recovery after electrically evoked isometric contraction of the vastus lateralis.

Effect of Creatine Supplementation on Performance

Many studies have examined the effect of creatine supplementation on muscle performance. These studies are separated into two broad categories to better organize this review: non-cycling and cycling related studies. In the non-cycling studies, creatine supplementation increased the amount of work completed during five bouts of 30 maximal voluntary knee extensions, with each bout separated by 60 seconds of passive rest (Greenhaff, Bodin, Soderlund, & Hultman, 1993). Similarly, creatine ingestion led to better maintenance of target speed, and hence, increased total work during 10 repeated six second bouts of maximal exercise that were separated by 30 seconds of passive recovery (Balsom et al., 1993). Creatine ingestion also increased the amount of work completed by elite kayakers during 90 seconds, 150 seconds, and 300 seconds of kayak ergometry and by weight lifters during five sets of bench press at a fixed load (McNaughton, Dalton, & Tarr, 1998; Volek et al., 1997). Aside from improving total work, creatine ingestion increased peak strength, measured by one repetition maximum bench press, and a set of five jump squats (Earnest et al., 1997; Volek et al., 1997).

As with the aforementioned non-cycling studies, creatine ingestion also enhanced muscular performance during cycling activities, typically measured with the cycle ergometer. Several studies show that creatine ingestion improves total work, and in some cases, peak power output during repeated 30 second bouts of cycling (Casey et al., 1997; Earnest et al., 1997; Birch et al., 1994). The mean increase in total work across the studies was approximately 8%, but it did vary widely. In one study total work increased by approximately 16% during a series of three consecutive 30 second Wingate tests separated by five minutes of rest (Earnest et al., 1997). In the other two studies, total work only increased by about 4% during three, 30 second bouts of maximal isokinetic cycling separated by four minutes of passive recovery (Birch et al., 1994), or two, 30 second Wingate tests separated by four minutes of passive rest (Casey et al., 1996). In these latter two studies, peak power output also increased by about 5% after creatine supplementation.

As with 30 second cycling bouts, creatine ingestion also improved performance during short repeated bouts of cycle ergometry. Total work during the first half of 12, six second sprints separated by 30 seconds of rest increased by nearly 51% after creatine ingestion (Kreider et al., 1997). Similarly, creatine supplementation reduced fatigue by 28% during a 10 second sprint, indicated by maintenance of higher pedaling frequency (Balsom et al., 1995).

Mechanism for Improved Performance

The ergogenic effect of creatine supplementation is possibly due to an increase in the skeletal muscle's ability to sustain ADP phosphorylation during exercise. This enhanced ability to sustain ADP phosphorylation may be the result of increased pre-exercising PCr availability, an improved buffering capacity, or an accelerated rate of PCr resynthesis during exercise and recovery, or some combination of these factors (Casey et al., 1996). The most widely touted mechanism combines several of the aforementioned scenarios. In short, creatine ingestion increases muscle creatine content, thereby accelerating PCr resynthesis between exercise bouts. As a result, the required rate of ADP phosphorylation is sustained longer after supplementation (Balsom et al., 1994; Brannon, Adams, Conniff, & Baldwin, 1997; Earnest et al., 1997; Greenhaff et al., 1994). Creatine supplementation, for example, has been shown to accelerate PCr resynthesis during recovery from intense electrically evoked isometric muscle contractions in man (Greenhaff et al., 1994). Similarly, creatine ingestion reduced muscle ATP loss by 30% after two Wingate tests separated by four minutes of recovery, suggesting that ADP phosphorylation was improved by supplementation (Casey et al., 1996).

Lack of Ergogenic Effect

Not all experiments, however, found that creatine supplementation improved performance, even if supplementation increased muscle total creatine content (TCr) (Balsom, Harridge, Soderlund, Sjodin, & Ekblom, 1993; Greenhaff, Bodin, Harris, Hultman, Jones, McIntyre, Soderlund, & Turner 1993; Odland, Macdougall,

Tarnopolsky, Elorriaga, & Borgmann, 1997; Terrillion, Kolkhorst, Dolgner, & Joslyn, 1997). Two factors that may account for this negative result are the nature of the work bout and the subjects' initial muscle TCr level. Creatine ingestion, for example, did not affect performance if the work or test bout was longer than 30 seconds, i.e., if it required a significant contribution from the aerobic metabolic pathways of ATP production (Dawson et al., 1995; Febbraio, Flanagan, Snow, Zhao, & Carey, 1995; Balsom et al., 1993). Similarly, creatine supplementation had no effect on single bouts of 30 second exercise (Odland et al., 1997; Ruden et al., 1996). In contrast, creatine ingestion did improve performance when the work bout was less than 30 seconds and it was performed at least twice (Bosco, Tihanyi, Pupcspk, Kovacs, Gabossy, Pulvirenti, Tranquilli, Foti, Viru, & Viru, 1997; Brannon et al., 1997; Earnest et al., 1997; Harris, Viru, Greenhaff, & Hultman, 1993; Kreider et al., 1997; Volek, Kraemer, Bush, Boetes, Incledon, Clark, & Lynch, 1997). Thus, the effectiveness of creatine supplementation is most evident during short-term, high intensity activities that involve repeated efforts interspersed with sufficient recovery time to permit PCr resynthesis (Earnest et al., 1997).

Another possible explanation for the discrepancies among studies is the subjects' initial muscle creatine concentration. Recent data reveal that the mean skeletal muscle creatine concentration is 125 mmol per kg of dry muscle (dm), with a normal range between 90 and 160 mmol per kg dm (Balsom et al., 1994). Additional data show that a TCr increase of >20 mmol per kg dm or about 8% is required to improve PCr resynthesis, and hence, exercise performance (Casey et al., 1996; Englehardt et al., 1998;

Green et al., 1996; Greenhaff et al., 1994). The wide range for skeletal muscle creatine concentration and the magnitude of the increase needed to increase performance may explain why some, but not all studies have shown the ergogenicity of creatine supplementation. In one study, for example, approximately half the subjects had pre-treatment creatine concentrations of < 125 mmole per kg dm (vegetarians had the lowest values). After supplementation, those individuals with the lowest TCr values exhibited the greatest increase in muscle creatine concentration, PCr regeneration, and performance (Greenhaff et al., 1994). In contrast, subjects with baseline creatine levels near the physiologic maximum, did not respond to creatine supplementation, as muscle creatine levels could not be increased by the required 8% (Clark, 1997). Individuals with such high baseline values are classified as "nonresponders", and may represent nearly 30% of most subject cohorts (Clark, 1997).

Summary

Creatine is an amino acid compound that exists in skeletal muscle and provides the body with a source of anaerobic energy. The creatine phosphate system fuels muscle contraction during short duration, high-intensity exercise that lasts 10-15 seconds. Creatine supplementation can increase TCr and PCr stores 10-20% and 20-40%, respectively. In addition, creatine supplementation enhances short duration, high-intensity exercise performance, possibly by increasing ATP production, or accelerating the rate of PCr resynthesis during and following the bouts of exercise. Supplementation seems to be most effective in enhancing performance in work to rest ratios of 1: 5 or

greater. Creatine supplementation will not augment performance for individuals with high pre-existing creatine stores; supplementation will also not enhance endurance performance.

Chapter 3

METHODS

Subjects

Fourteen trained male cyclists (age range 18-40 y) were recruited. All subjects had a minimum of two years of competitive cycling experience which included racing no less than six times per year. Each subject was informed of the risks associated with the procedures, and signed a letter of informed consent prior to participation. The Human Subjects Review Committee at Ithaca College approved all procedures.

Procedures

Subjects were tested on five occasions, each separated by at least three days of rest. The tests included a: 1) Wingate anaerobic power test, 2) maximal oxygen consumption test, 3) recovery test 1, 4) recovery test 2, and 5) recovery test 3. A mechanically braked cycle ergometer (Monark 818*E*, Monark Corp., Sweden) that was modified with an InstaLoad Friction Belt (Sports Medicine Industries, Inc., St. Cloud, MN), racing saddle, drop handlebars, and the subject's pedal system was used in all tests. The saddle height on the ergometer was adjusted to produce a 10 degree knee angle at full leg extension. All tests were preceded by a three hour fast and 10 minutes of cycling at 200 W; each test was also followed by 5 minutes of cycling against minimal resistance. Subjects were also instructed to refrain from strenuous physical activity during the 24 hours that preceded a test.

Wingate Anaerobic Power Test

On test day one, subjects completed a Wingate anaerobic power test. Immediately prior to the test, the subject was given a five second count, during which he tried to obtain his maximal cadence. At zero seconds, the test began when a load equivalent to 7.5% of the cyclist's body mass was applied as resistance. The subject remained seated and was given vigorous verbal encouragement during the test (Bar-Or, 1987). Mean, maximum, and minimum power, as well as percent fatigue, were recorded with the Optisensor 2000 (Sports Medicine Industries, Inc., St. Cloud, MN) linked to a computer.

Maximum Oxygen Consumption

On test day two subjects completed a continuous exercise protocol to determine maximum oxygen consumption (VO_2max). The initial workload was 200 W and was increased 40 W every two minutes until the prescribed cadence of 80 ± 3 RPM could not be maintained. Oxygen consumption was measured using open circuit spirometry with a computerized metabolic cart (SensorMedics 2900, Yorba, Linda CA) and heart rate via telemetry (Polar Instruments Inc., Oulu, Finland). Perceived exertion was obtained at the end of each two-minute stage using the Borg scale (Borg, 1957). Five minutes prior to, and three minutes following the VO_2max test, a 25 *ul* blood sample was drawn from the fingertip and analyzed for lactate concentration (YSI 1500 Sport Tester, Yellow Springs, OH).

Recovery Test Protocol

Three days prior to the first recovery test, subjects were familiarized with the procedures by completing three maximum, 45 second exercise bouts separated by 45 seconds of low intensity active recovery. The familiarization test was conducted to minimize any learning effects associated with the protocol. In the recovery tests, subjects completed four bouts of high intensity cycling separated by a brief period of active recovery of either 45, 90 or 135 seconds. Only one recovery period was used on a given test day. The order of the recovery periods was assigned randomly to minimize possible learning and training effects. The high intensity cycling bouts were completed in the same fashion as the Wingate test except the bout was 45 seconds and the resistance was 5.5% of body mass. The resistance for the active recovery period was 2.5% of body mass and pedal frequency was 80 rpm. The resistance levels were derived from a pilot study (N = 5), which determined a higher resistance level did not allow the subjects to complete all four cycling bouts. During all tests, heart rate, VO_2, work, and power output were measured as previously described. Percent fatigue was measured within each 45 second work bout, and across bouts 1 and 4. In addition, 25 *u*l blood samples were obtained five minutes prior to, immediately following the second supramaximal exercise bout, and three minutes following the fourth bout to determine blood lactate concentration as previously described.

Creatine Administration

After the VO_2max test, subjects were randomly assigned to a creatine (Cr) or placebo condition. A double-blind protocol was used. The Cr group consumed creatine (Phosphagen HP, Experimental and Applied Sciences Co., Golden CO.) and the placebo group consumed a Phosphagen HP placebo. Subjects supplemented in two phases. During the first phase, or the loading phase, both groups were instructed to consume 5 g of product, five times a day for five days. Each 5 g dose was dissolved in 1000 ml of warm water and taken at regular intervals during the day. After the loading phase, the subjects began the maintenance phase, in which they consumed 5 g of product daily until the last day of testing (about 4 weeks). The amount of creatine consumed has been shown to increase and maintain intramuscular TCr stores (Greenhaff et al., 1994; Harris et al., 1992).

Supplement packets were administered in coded boxes containing a five-day supply of product. Supplementation for either phase was verified by having the subjects return the empty product packets. No subject began the maintenance phase without fully completing the loading phase. Subjects were asked to maintain their normal diet and to avoid any other nutritional supplements, proposed ergogenic aids, and nonprescriptive drugs during the course of the study.

Blood Sampling

On test day 2 (VO_2max test) a 25 *ul* blood sample was drawn from the fingertip(s) five minutes prior to, and three minutes following the cycle test for determination of blood lactate concentration. On test days 3 to 5, 25 *u*l blood samples were obtained five minutes prior to, immediately following the second supramaximal exercise bout, and three minutes following the fourth bout to determine blood lactate concentration.

Urinary Creatinine Excretion Analysis

Urinary creatinine excretion was measured following completion of the loading phase so that loading could be further verified. A 24 hour urine sample was collected from each subject. Urinary creatinine level was measured with a colometric analysis developed by Sigma Diagnostics (Sigma Diagnostics, Inc. St. Louis MO).

Statistical Analyses

A three-way repeated measures analysis of variance (ANOVA) for groups (2), recovery period (3), and exercise bout (4) was used to analyze the dependent variables of peak power, mean power, blood lactate, percent fatigue, HR, and VO_2. Simple main effects were evaluated with a post-hoc Tukey HSD. Descriptive statistics included anaerobic power, VO_2max, years of training, age, height, and weight.

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Chapter 4

RESEARCH MANUSCRIPT

INTRODUCTION

The ability of creatine supplementation to enhance cycling performance is shown by studies that report improved power output during short, repeated bouts of high intensity cycling (Balsom et al., 1995; Balsom et al., 1993; Birch et al., 1994; Casey, Constantin-Teodosiu, Howell, Hultman, & Greenhaff, 1996; Dawson, Cutler, Moody, Lawrence, Goodman, & Randall, 1995; Earnest et al., 1997; Kreider et al., 1997). The extension of these findings to the competitive cycling arena, however, is limited by several factors. First, none of the subjects in the aforementioned studies were trained cyclists. Second, passive rather than active recovery was used in these studies; the opportunity for passive recovery rarely occurs during competitive road cycling. Another factor that limits the applicability of these studies to the competitive arena is the short duration of the cycling bouts, which lasted for less than 10 seconds in several studies (Balsom et al., 1993; Balsom et al., 1995; Kreider et al., 1997). In road racing, cyclists often perform several consecutive 30 to 60 second high intensity efforts during a series of attacks or for the final sprint set-up. Thus, it remains to be seen if creatine supplementation benefits a trained cyclist in a more applied setting. Hence, one purpose of this study was to determine if creatine supplementation improves performance in trained cyclists who complete repeated bouts of high intensity cycling of a length more characteristic of the sport.

Whereas the ability of creatine to increase power output during repeated bouts of high intensity exercise is well documented, there is little information on the minimum recovery time needed between work bouts to maintain power output. A work to rest ratio of 1:5 has been used in many studies (Balsom et al., 1993; Balsom et al., 1995; Birch et al., 1994; Earnest et al., 1997; Kreider et al., 1997). However, a shorter work to rest ratio of 1:2 was used by Greenhaff et al. (1993). They demonstrated that PCr resynthesis was increased by 42% during the second minute of recovery following creatine supplementation, a finding that suggests a shorter work to rest ratio may also enhance performance. Therefore, another purpose of this study was to compare the effects of recovery time on power output during repeated bouts of high intensity exercise following creatine supplementation.

METHODS

Subjects. Fourteen trained male cyclists (age range 18-40 y) were recruited (Appendix E). Physical and training characteristics are presented in Table 1. All subjects had a minimum of two years of competitive cycling experience (Appendix A). Each subject was informed of the risks associated with the procedures, and signed a letter of informed consent prior to participation (Appendices B, C). The Human Subjects Review Committee at Ithaca College approved all procedures.

Procedures. Subjects were tested on five occasions, each separated by at least three days of rest. The tests included a: 1) Wingate anaerobic power test, 2) maximal oxygen consumption test, 3) recovery test 1, 4) recovery test 2, and 5) recovery test 3. A mechanically braked cycle ergometer (Monark 818*E,* Monark Corp., Sweden) modified with an InstaLoad Friction Belt (Sports Medicine Industries, Inc., St. Cloud, MN), racing saddle, drop handlebars, and the subject's pedal system was used in all tests. The saddle height on the ergometer was adjusted to produce a 10 degree knee angle at full leg extension. All tests were preceded by a three-hour fast and 10 minutes of cycling at 200 W; each test was also followed by 5 minutes of cycling against minimal resistance. Subjects were instructed to refrain from strenuous physical activity during the 24 hours that preceded a test.

Wingate Anaerobic Power Test. On test day one, subjects completed a Wingate anaerobic power test. At zero seconds, the test began at a load equivalent to 7.5% of body mass (Bar-Or, 1987). Mean, maximum and minimum power, as well as percent fatigue, were recorded (Appendix D) with the Optisensor 2000 (Sports Medicine Industries, Inc., St. Cloud, MN) linked to a computer.

Maximum Oxygen Consumption. On test day two subjects completed a continuous exercise protocol to determine maximum oxygen consumption (VO_2 max). The initial workload was 200 W and was increased 40 W every two minutes until the prescribed cadence of 80 ± 3 RPM could not be maintained (Appendix D). Oxygen consumption was measured using open circuit spirometry with a computerized metabolic cart

(SensorMedics 2900, Yorba, Linda CA) and heart rate via telemetry (Polar Instruments Inc., Oulu, Finland). Perceived exertion was obtained at the end of each two-minute stage using the Borg scale (Borg, 1957). Five minutes prior to, and three minutes following the VO_2max test, a 25 *u*l blood sample was drawn from the fingertip and analyzed for lactate concentration (YSI 1500 Sport Tester, Yellow Springs, OH).

Recovery Test Protocol. Three days prior to the first recovery test, subjects were familiarized with the procedures by completing three maximum, 45 second exercise bouts separated by 45 seconds of low intensity active recovery. In the recovery tests, subjects completed four bouts of high intensity cycling separated by a brief period of active recovery of either 45, 90 or 135 seconds. Only one recovery period was used on a given test day. The high intensity cycling bout was 45 seconds and the resistance was 5.5% of body mass. The resistance for the active recovery period was 2.5% of body mass and pedal frequency was 80 rpm. The resistance levels were derived from a pilot study (N = 5), which determined a higher resistance level did not allow the subjects to complete all four cycling bouts. During all tests, heart rate, VO_2, work, blood lactate, and power output were measured as previously described. Percent fatigue was measured within each 45 second work bout, and across bouts 1 to 4 (Appendix D).

Creatine Administration. After the VO_2max test, subjects were randomly assigned to a Cr or placebo condition. A double-blind protocol was used. The Cr group consumed creatine (Phosphagen HP, Experimental and Applied Sciences Co., Golden CO.) and the placebo group consumed a Phosphagen HP placebo. Subjects supplemented in two

phases. During the first phase, or the loading phase, both groups were instructed to consume 5 g of product, five times a day for five days. After the loading phase, the subjects began the maintenance phase, in which they consumed 5 g of product daily until the last day of testing (about 4 weeks). The amount of creatine consumed has been shown to increase and maintain intramuscular TCr stores (Greenhaff et al., 1994; Harris et al., 1992).

Supplement packets were administered in coded boxes containing a five-day supply of product. Supplementation for either phase was verified by having the subjects return the empty product packets. No subject began the maintenance phase without fully completing the loading phase. Subjects were asked to maintain their normal diet and to avoid any other nutritional supplements, proposed ergogenic aids, and nonprescriptive drugs during the course of the study.

Urinary Creatinine Excretion Analysis. Urinary creatinine excretion was measured following completion of the loading phase so that loading could be further verified. A creatinine kit designed by Sigma Diagnostic Laboratories was utilized to measure urinary creatinine excretion over a 24 hour period (Sigma Diagnostics, Inc. St. Louis MO).

Statistical Analyses. A three-way repeated measures analysis of variance (ANOVA) for groups (2), recovery period (3), and exercise bout (4) was used to analyze the dependent variables of peak power, mean power, blood lactate, percent fatigue, HR, and VO_2. Simple main effects were evaluated with a post-hoc Tukey HSD. Descriptive statistics

included anaerobic power, VO_2max, years of training, age, height, and weight. ANOVA tables appear in Appendix D, and raw data in Appendix E.

RESULTS

Peak Power Output. Peak power output for each 45 second cycling interval was measured and calculated as the average power output for the first five seconds of each bout. As shown in Table 2 and Figure 1, there was no significant difference in peak power output between groups or recovery tests ($p>0.05$). As expected there was an 11% decrease in peak power output across bouts ($p>0.05$).

Mean Power Output. Mean power output was measured during each cycling bout and calculated as the average power output during the entire 45 second bout. As shown in Table 3 and Figure 2, there was no significant difference in mean power output between groups or recovery tests ($p>0.05$). Mean power decreased 7% across four bouts ($p<0.05$).

Percent Fatigue. Percent fatigue was measured for each 45 second cycling bout and across bouts 1 and 4 for each recovery test. On average the Cr and placebo group showed a 23% decrease in power output. As shown in Figure 3, there was no difference between the two groups for any cycling bout or recovery test.

Blood Lactate. In the recovery tests, blood lactate concentration was measured pre-exercise, immediately post cycling bout 2, and three minutes after exercise bout 4. A three-way ANOVA analyses revealed a significant difference ($p<0.05$) for this variable. Subsequent post-hoc analyses showed that the Cr group had a lower blood lactate concentration after bout 2 as shown in Table 4 and Figure 4. There were no other

differences in blood lactate concentration for this study.

Body Mass, Heart Rate, and Oxygen Consumption. There were no significant differences in body mass across time or between groups during the study, although the Cr group did gain 3.5% more mass compared to the placebo group. As shown in Tables 5 and 6, there were no differences in HR or VO_2 between groups or recovery tests ($p>0.05$).

Creatinine Excretion. Urinary creatinine excretion was measured over a 24 hour period. The sample was collected from all subjects immediately upon completion of the five day loading phase of supplementation. Mean urinary volume was 1843 ml and not different between groups. The Cr group had a 92% higher creatinine excretion than the placebo group ($p < 0.05$).

Table 1

Physical and Training Characteristics (mean ± SD) of Subjects (N=14)

Variable	Group Creatine	Placebo	P-value
Age (y)	25.2 ± 5.92	22.7 ± 4.86	.105
Years Training	7.3 ± 4.60	4.2 ± 2.89	.138
Weight (kg)			
pre	72.4 ± 8.10	70.1 ± 9.48	.203
post	72.1 ± 8.32	70.6 ± 9.85	.187
Height (cm)	169.4 ± 9.54	169.6 ± 9.02	.124
Body Fat %[a]			
pre	9.1 ± 4.09	9.0 ± 3.59	.165
post	9.7 ± 4.28	8.7 ± 3.86	.159
Fat Free Mass (kg)			
pre	66.2 ± 9.04	64.9 ± 9.87	.185
post	65.8 ± 9.59	64.3 ± 9.95	.181
Anaerobic Power (W)	887.6 ± 89.75	887.8 ± 99.50	.093
VO_2 max ($ml \cdot kg^{-1} min^{-1}$)	61.5 ± 4.70	58.7 ± 5.00	.107

Note.[a] Body fat % calculated using a seven site skinfold test (Jackson & Pollock, 1985).

Table 2

Peak power output (mean ± SEM) for each bout during three recovery tests.

	Peak Power (W)			
	Bout			
	Placebo Group (n=7)			
Recovery Test	1	2	3	4
45-sec	604.3 ± 31.96 *	497.3 ± 26.02 #	466.9 ± 24.70	462.8 ± 29.16
90-sec	587.6 ± 35.05 *	517.5 ± 26.11 #	473.2 ± 19.65	484.3 ± 29.84
135-sec	615.7 ± 34.67 *	519.2 ± 32.66 #	478.1 ± 22.14	482.7 ± 22.14
	Creatine Group (n=7)			
45-sec	665.2 ± 41.53 *	571.0 ± 32.20 #	531.2 ± 30.42	537.8 ± 20.45
90-sec	666.7 ± 57.78 *	582.2 ± 41.49 #	550.2 ± 36.24	527.5 ± 27.26
135-sec	658.4 ± 44.21 *	599.9 ± 40.32 #	538.5 ± 35.33	538.3 ± 26.74

Note. One subject in the creatine group did not complete bout four of the 45 second recovery test. Peak power was calculated as the average power output during the first five seconds of each bout.

* = bout 1 greater than bouts 2, 3, & 4 ($p<0.05$). # = bout 2 greater than bouts 3 & 4 ($p<0.05$).

Table 3

Mean power output (mean ± SEM) for each bout during three recovery tests.

	Mean Power (W)			
	Bout			
	Placebo Group (n=7)			
Recovery Test	1	2	3	4
45-sec	515.2 ± 25.44 *	426.5 ± 25.47	391.1 ± 21.36	384.3 ± 24.79
90-sec	517.8 ± 23.49 *	439.7 ± 19.95	409.6 ± 17.58	401.2 ± 15.44
135-sec	516.4 ± 24.89 *	440.0 ± 24.14	404.5 ± 16.15	406.9 ± 20.94
	Creatine Group (n=7)			
45-sec	548.3 ± 28.36 *	466.7 ± 22.55	419.0 ± 21.30	429.9 ± 15.97
90-sec	547.9 ± 35.69 *	474.2 ± 27.30	441.3 ± 24.65	431.6 ± 19.89
135-sec	545.4 ± 30.61 *	493.7 ± 27.64	452.8 ± 26.38	439.5 ± 20.46

Note. One subject in the creatine group did not complete bout four of the 45 second recovery test. Mean power was calculated as the average power output during the entire 45 second bout.

* = bout 1 greater then bouts 2, 3, & 4 ($p < 0.05$).

Table 4

Blood lactate (mean ± SEM) for each bout during three recovery tests.

	Blood Lactate (mM)		
	Bout		
	Placebo Group (n=7)		
Recovery Test	Pre Exercise	Post Bout 2	Post Exercise
45-sec	1.93 ± 0.72 *	14.34 ± 5.41	17.98 ± 6.78
90-sec	1.73 ± 0.65 *	14.22 ± 5.37	17.81 ± 6.72
135-sec	1.93 ± 0.73 *	14.34 ± 5.41	17.98 ± 6.78
	Creatine Group (n=7)		
45-sec	1.62 ± 0.66 *	11.89 ± 4.85	19.36 ± 7.31
90-sec	1.81 ± 0.74 *	14.79 ± 6.04	18.63 ± 7.03
135-sec	1.85 ± 0.76 *	14.66 ± 5.98	17.77 ± 6.71

Note. One subject in the creatine group did not complete bout four of the 45 second recovery test. Blood lactate was measured five minutes before exercise began, immediately post exercise bout 2, and three minutes post exercise.

* = bout 1 significantly lower then bout 3 ($p < 0.05$).

Table 5

Heart rate (mean ± SEM) for each bout during three recovery tests.

	Bout			
	Placebo Group (n=7)			
Recovery Test	1	2	3	4
45-sec	189.88 ± 2.39	187.42 ± 2.63	188.24 ± 2.32	188.54 ± 2.38
90-sec	185.71 ± 2.86	186.89 ± 2.79	189.61 ± 3.15	188.90 ± 3.29
135-sec	184.84 ± 2.57	185.90 ± 3.48	188.65 ± 3.09	188.20 ± 3.00
	Creatine Group (n=7)			
45-sec	186.00 ± 2.45	187.70 ± 2.81	188.42 ± 2.13	187.83 ± 2.98
90-sec	182.42 ± 3.05	185.00 ± 2.95	186.71 ± 3.24	187.85 ± 3.45
135-sec	184.14 ± 2.65	186.85 ± 3.51	187.00 ± 3.00	187.42 ± 3.09

Note. One subject in the creatine group did not complete bout four of the 45 second recovery test.

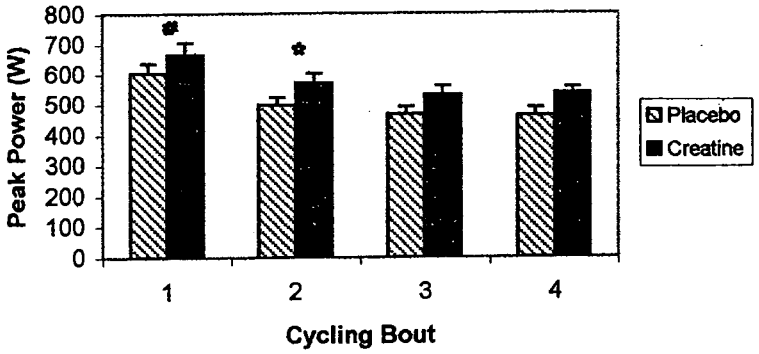
Table 6

Oxygen consumption (mean ± SEM) for each bout during three recovery tests.

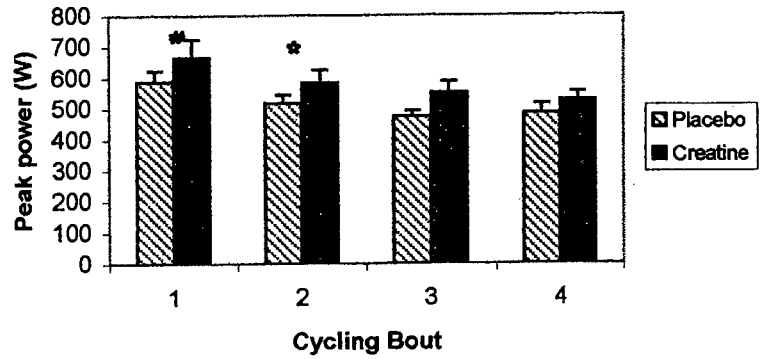
	Bout			
	Placebo Group (n=7)			
Recovery Test	1	2	3	4
45-sec	52.76 ± 1.23	51.74 ± 1.19	53.24 ± 1.21	53.08 ± 1.17
90-sec	54.23 ± 1.17	54.11 ± 1.12	54.00 ± 1.24	55.04 ± 1.23
135-sec	53.12 ± 1.15	53.98 ± 1.20	55.78 ± 1.28	55.68 ± 1.21
	Creatine Group (n=7)			
45-sec	51.75 ± 1.09	48.65 ± 1.14	48.39 ± 1.08	55.33 ± 1.17
90-sec	52.11 ± 1.10	49.13 ± 1.05	57.05 ± 1.09	54.67 ± 1.12
135-sec	51.99 ± 1.18	56.89 ± 1.17	56.19 ± 1.10	54.19 ± 1.14

Note. One subject in the creatine group did not complete bout four of the 45 second recovery test.

45-sec recovery test



90-sec recovery test



135-sec recovery test

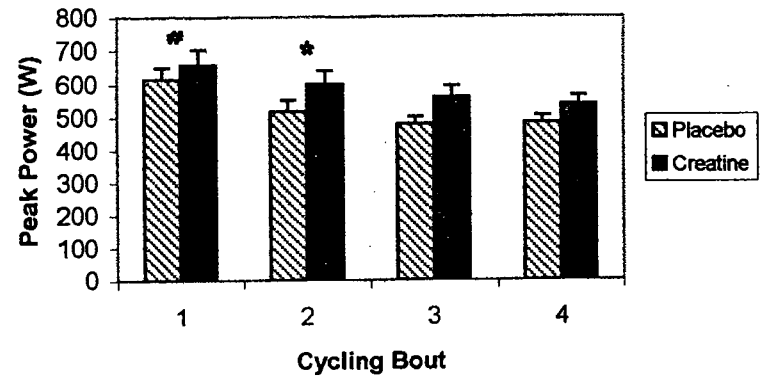
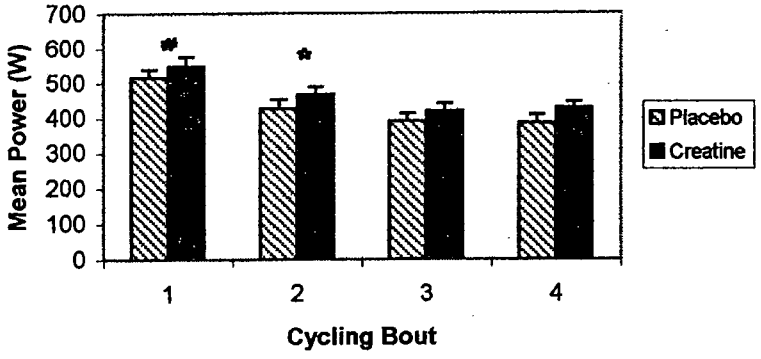
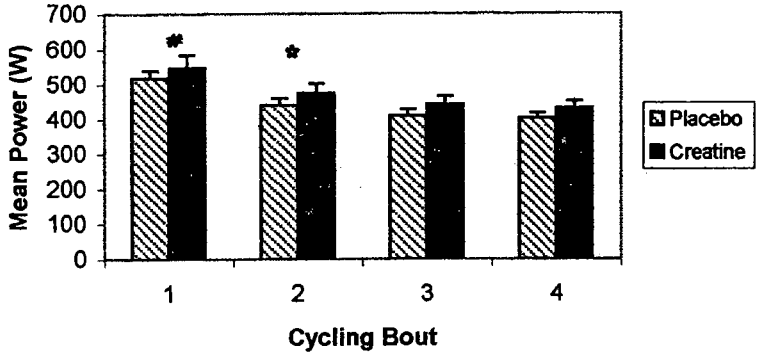


Figure 1. Peak power (mean ± SEM) for groups during four bouts of 45-sec supramaximal cycling exercise. Subjects cycled maximally at 5.5% of body weight during each bout. Repeated bouts were separated by an active recovery period in which subjects cycled at 70-80 rpm at 2.5% of body weight. The active recovery periods were 45, 90, and 135 seconds. # = bout 1 greater than bouts 2, 3, & 4 in both groups ($p < 0.05$). * = bout 2 greater than bouts 3 & 4 in both groups ($p < 0.05$).

45-sec recovery test



90-sec recovery test



135-sec recovery test

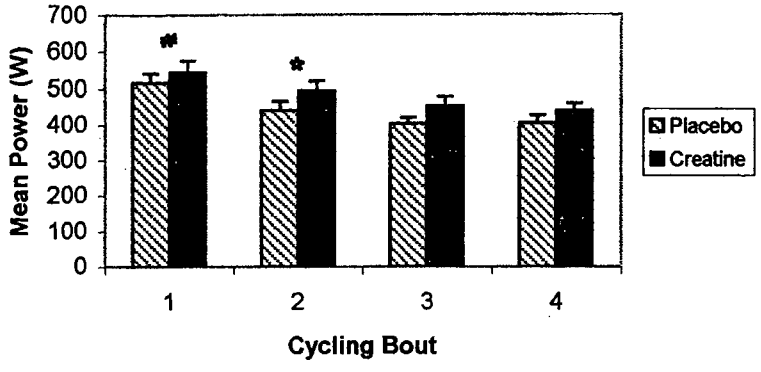


Figure 2. Mean power (mean ± SEM) for groups during four bouts of 45-sec supramaximal cycling exercise. Subjects cycled maximally at 5.5% of body weight during each bout. Repeated bouts were separated by an active recovery period in which subjects cycled at 70-80 rpm at 2.5% of body weight. The active recovery periods were 45, 90, and 135 seconds. # = bout 1 greater than bouts 2, 3, & 4 in both groups ($p < 0.05$). * = bout 2 greater than bouts 3 & 4 in both groups ($p < 0.05$).

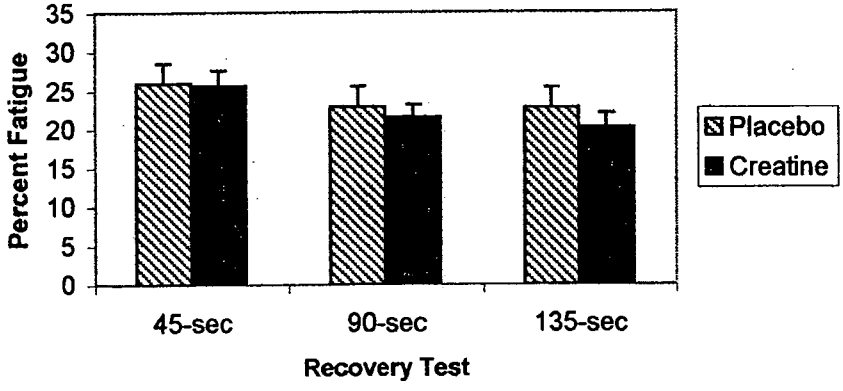
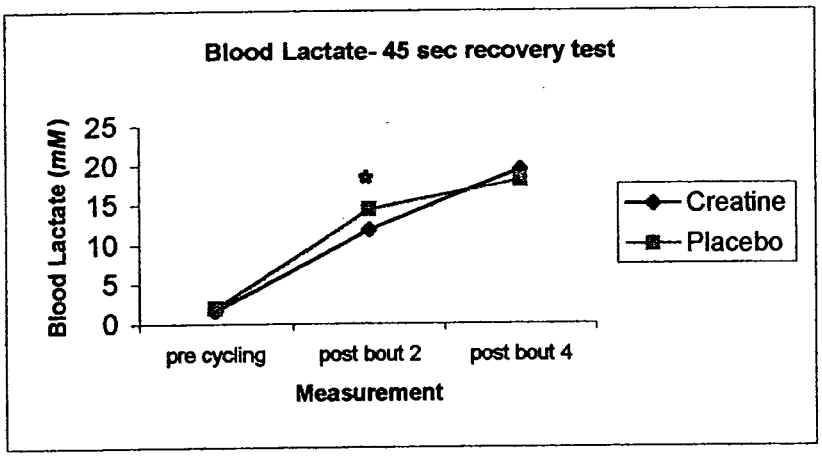
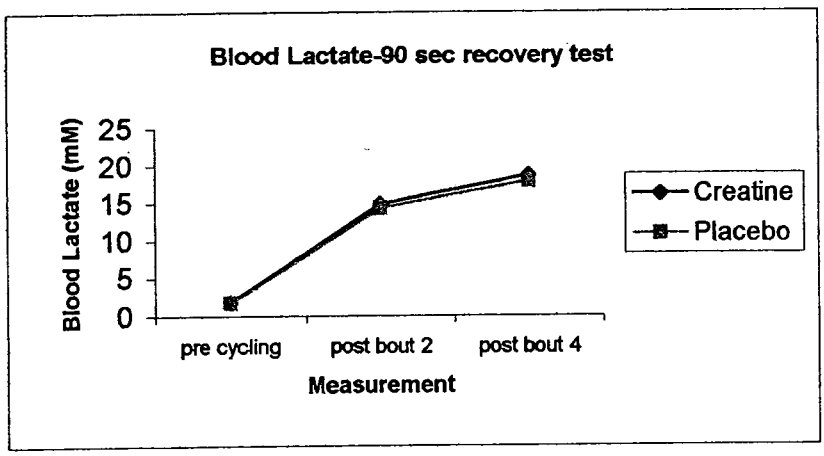


Figure 3. Fatigue (mean ± SEM) during four bouts of 45-sec supramaximal cycling exercise. Repeated bouts were separated by an active recovery period, during which subjects maintained 70-80 rpm at 2.5% of body weight. Fatigue was calculated as the ((highest-lowest mean power)/highest) X100.





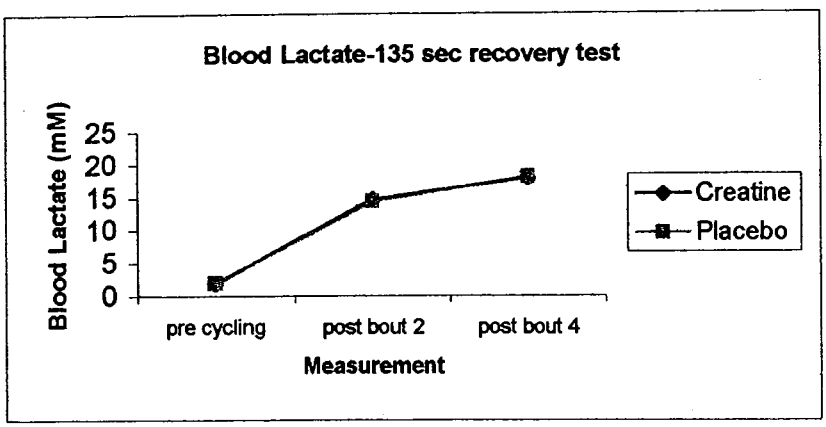


Figure 4. Blood lactate (mean ± SEM) for groups during four bouts of 45-sec cycling exercise. Measurements were taken five minutes before cycling began, supramaximal immediately post bout 2, and three minutes after completion of bout 4. * = significant difference between Cr and placebo ($p < 0.05$).

DISCUSSION

The primary purpose of this study was to determine if creatine supplementation affects recovery time during repeated bouts of high intensity cycling. To that end, well trained cyclists completed four, 45 second supramaximal cycling intervals separated by 45 seconds, 90 seconds or 135 seconds of active recovery, thereby yielding work to rest ratios of: 1:1, 1:2, and 1:3. This experimental design also permitted examination of the potential benefit of creatine supplementation to trained road cyclists, as the length of the lab test (45 s) was more characteristic of actual road racing than typically studied test durations of 6-10 seconds.

Data from this study show that there were no significant differences in peak or mean power between the groups for any work to rest ratio. These data are consistent with findings from several studies (Balsom et al., 1993; Dawson, Cutler, Moody, Lawrence, Goodman, & Randall, 1995; Febbraio, Flanagan, Snow, Zhao, & Carey, 1995), but conflict with data from many other studies (Balsom, Ekbolm, Soderlund, Sjodin, & Hultman, 1993b; Birch, Noble, & Greenhaff, 1994; Earnest, Snell, Rodriguez, Almada, & Mitchell; Harris, Soderlund, & Hultman, 1997; Zoeller, & Angelopoulos, 1998). Creatine supplementation also did not change the rate of fatigue across each exercise bout, or from bouts one to four for all recovery tests. These data are inconsistent with the data from other studies that show creatine supplementation decreases fatigue during short duration high-intensity exercise (Balsom, Ekbolm, Soderlund, Sjodin, & Hultman, 1993; Birch et al., 1994; Earnest et al., 1997).

The length of the work to rest ratio may partially explain the discrepancy in the data from the aforementioned studies in which repeated work bouts were used to determine the effect of creatine on power output and fatigue. In most studies that show creatine enhances power output or decreases fatigue during repeated bouts of high intensity exercise, the work to rest ratio is longer than 1:5 (Balsom et al., 1993; Balsom et al., 1995; Birch et al., 1994; Earnest et al., 1997; Kreider et al., 1997). One exception is the 1:2 work to rest ratio used by Greenhaff et al. (1993), whose data prompted the use of an even shorter work to rest ratio in this study. Since creatine supplementation had no effect on power output or fatigue in this study, but did so in studies with longer work to rest ratios, it is possible that the ratios in the present study were too short to show ergogenicity of creatine.

The results from this study may differ due to the nature of the work bout. In previous work, creatine supplementation did not improve performance when either a single work bout or multiple bouts longer than one minute were used (Febbraio et al., 1995; Balsom et al., 1993; Odland et al., 1997; Ruden et al., 1996). In contrast, creatine supplementation did enhance performance with repeated work bouts of less than 30 seconds (Balsom et al., 1995; Balsom et al., 1993; Birch et al., 1994; Casey et al., 1996; Dawson et al., 1995; Earnest et al., 1997; Kreider et al., 1997). Thus, the effect of creatine supplementation is best shown with repeated short-term bouts (30 seconds or less) of high intensity activity that are separated by sufficient recovery time. These are activities in which aerobic ATP contribution is minimal (Earnest et al., 1997). Since creatine supplementation did not affect power output or fatigue in this study, it is possible

that the repeated 45 second work bouts were too long and required too much aerobic ATP production to benefit from the potential ergogenicity of creatine.

An initial difference in intramuscular creatine stores is another factor that may partially explain why creatine supplementation did not alter performance. If a subject cohort contained a high number of individuals with baseline intramuscular creatine levels near the physiologic maximum of 160 $mmol \cdot kg^{-1}$ of dry muscle, the effect of creatine would be reduced. Such individuals are non-responders because their intramuscular creatine stores are not sufficiently elevated by creatine supplementation (Clark, 1997). Non-responders, moreover, typically represent 30% of most subject cohorts (Clark, 1997). The subject cohort in this study may have contained a high percentage of non-responders, as there was no significant change in body mass across time in the Cr group which is typically observed following creatine loading (Balsom, Ekbolm, Soderlund, Sjodin, & Hultman, 1993; Balsom, Harridge, Soderlund, Sjodin, & Ekbolm, 1993; Earnest, Snell, Rodriguez, Almada, & Mitchell; Harris, Soderlund, & Hultman, 1992; Volek, Kraemer, Bush, Boetes, Incledon, Clark, & Lynch, 1997).

Failure to consume the prescribed amount of creatine could also explain the lack of effect in the Cr group. The dosage was derived from studies in which creatine supplementation effectively enhanced performance (Balsom et al., 1994). The possibility of subject non-compliance is remote, however, as each packet of creatine was returned emptied and subjects self reported supplementation adherence. In addition, analysis of the post-loading creatinine data demonstrated that creatine uptake was maximized, suggesting full intramuscular stores. Unfortunately, muscle creatine levels were not

directly measured in this study. These creatinine data, however, are consistent with data reported elsewhere, in which the muscle creatine level was also measured to confirm creatine uptake (Greenhaff et al., 1993; Harris, Soderlund, & Hultman, 1992).

In contrast to the power and fatigue data, creatine supplementation altered lactate accumulation, but only after bout 2 in the 45 second recovery tests. The decrease in lactate after bout 2 in the 45 second recovery tests may have been due to increased muscle creatine levels. If muscle creatine is increased, energy release from the creatine phosphate energy cycle could have been maintained longer, thereby attenuating the increase in glycolysis, and subsequently, blood lactate. The lack of a significant difference in lactate after bout 4 in the 45 second tests and in the other tests may be due to the duration of the work and recovery periods. If the cycling bouts were shorter, this would decrease the necessary anaerobic and aerobic contributions to muscle energetics. Likewise, if the recovery periods were longer, PCr resynthesis would be enhanced. In either case, creatine supplementation could have altered lactate more consistently across all measurement periods and recovery tests. For example, creatine supplementation significantly alters blood lactate during 10 second work bouts (Balsom et al., 1995). In contrast, the significant decrease in lactate after bout 2 in the 45 second recovery test may not have been a result of creatine supplementation. Instead, it is possible that muscle lactate was not cleared sufficiently after bout 2 in the 45 second recovery tests, and elevated blood lactate. If so, this might explain why there was no difference between the groups after bout 4 in the 45 second recovery tests.

Summary. In conclusion, these results indicate that creatine supplementation did not enhance peak or mean power production during repeated supramaximal cycling bouts. In addition, creatine loading did not favorably alter HR, VO_2, or the rate of fatigue. Based on these data, creatine supplementation is not indicated for high intensity activities that are 45 seconds in duration or longer.

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Appendix A

CREATINE SUPPLEMENTATION QUESTIONNAIRE

Name: _____ Age:_____

Local Address: _____

Local Phone: _____

Birth Date: _____ Sex: M / F Weight (lbs.):_____

E-mail: _____

How long have you been cycling consistently?_____

How many days per week do you ride? Less than 2 _____ 2-4 _____ 4-7 _____

What percentage of your cycling is? Sprinting _____ Distance _____

Mountain Biking _____

On average, how many miles per week do you ride? _____

How many caffeinated beverages do you consume daily? _____

Have you used any form of creatine supplementation within the last six months? Yes / No

If so, when did you stop taking the supplement? _____

_____

Are you currently taking any other form of ergogenic aid, legal or illegal? Yes / No

Are you a vegetarian? Yes / No

Appendix B

INFORMED CONSENT FORM

Effects of creatine supplementation on power output during repeated bouts of supra-maximal cycling.

1. Purpose of the study:

The purpose of this study is to investigate the effects of oral creatine monohydrate on recovery from repeated bouts of supra-maximal cycling.

2. Benefits of the study:

By participating in the study you will learn if creatine monohydrate actually enhances cycling performance. You will also learn your VO_2 max, the best single predictor of a person's work capacity. This knowledge can be very valuable for training in the most efficient manner.

3. Your Participation Requires:

You will report to the laboratory for 6 days. **Days 1 & 2:** On the first 2 days you will become familiarized with the equipment and testing protocol. **Day 3:** The third day you will complete a VO_2 max test, which requires about 8-15 minutes of cycling. In this test you will pedal a cycle ergometer until volitional fatigue, and you will wear a headgear device with a 2-way breathing valve so that we can measure your expired gases. After the third test day you will take a supplement 5 times per day for 5 days, then one time per day until the last test day (approximately 4 weeks). **Days 4-6:** On the following three test days, after supplementation, you will ride a cycle ergometer at maximum intensity for 4 repeated bouts lasting 45 seconds. The repeated bouts of maximum effort cycling will be interrupted by active recovery intervals between 45-135 second long. Recovery time following each bout of exercise will be the same on each test day but will vary between 45, 90, and 135 seconds. On test day 3 (VO_2 max) a small (25 *u*l) blood sample will be drawn from the fingertip(s) 10 minutes prior to and immediately following the second cycle test and analyzed for blood lactate concentration. On days 4-6, blood samples (25 *u*l) will be obtained 10 minutes prior to, following the second supramaximal exercise bout, and immediately following the testing to determine blood lactate concentration. Each test session will be 30-60 minutes long.

4. Risks of participation:

The risks associated with this test protocol are minimal. For maximal exercise testing in a healthy population the ACSM has recorded one event per 187,500 hours of testing, and one death per 396,000 hours of testing. This figure includes individuals who are trained as well as untrained. There is a possibility of muscle soreness, particularly 24 to 48 hours after an exercise test. There is also a small chance of musculosketetal injury associated with vigorous exercise.

_____

Subject's Initials

Appendix B (Con't.)

In addition, you may experience some soreness in your fingertips from where the blood is drawn. A short-term creatine monohydrate supplementation regimen of 25 grams per day for 5-6 days has been reported to have no known side effects, providing creatine is dissolved prior to ingestion. Undissolved creatine may cause slight gastrointestinal discomfort. Further, the maintenance dose of creatine currently advocated (5 g per day) to maintain muscle creatine concentration is no greater than that found in some meat-eaters' diets. There has been anecdotal evidence that creatine consumption causes muscle cramps or strains, but there is no scientific evidence to support these claims.

5. If you would like more information about this study at any time prior to, during, or following the data collection, you may contact Brian Kelly, at (315) 252-7770 or Betsy Keller at (607) 274-1683.

6. Withdrawal from the study:

You are free to withdraw from this study at anytime without penalty. I would appreciate it if you would inform me of your decision should you decide to do so.

7. Confidentiality:

All data collected in this study will be coded to insure your confidentiality. Your name will not appear in any reports from this study.

I have read and understand the above document. I agree to participate in this study and realize that I can withdraw at any time. I also understand that I can and should address questions related to this study at any time to the researchers involved. I also verify that I am at least 18 years of age.

_____

Name of Subject (please print)

_____ _____

Signature of Subject Date

Appendix C

MEDICAL HISTORY / HEALTH HABIT QUESTIONNAIRE

Name _____ Age_____ Date of Birth _____

Home Address_____ Phone # _____

Work Address_____ Phone #_____

Physician _____

Family History: Have any blood relatives had? (sister, brother, etc.)

Heart Disease ( ) Stroke ( ) Diabetes ( ) High blood pressure ( )
High Cholesterol ( )

Other Conditions/Comments:

Medical/Health History: Check if you have ever had:

Hear Disease/Stroke ------
High Blood Pressure ------
Heart Murmur --------
Rheumatic Fever -------
Skipped, rapid beats, or
irregular rhythm --------
Cancer ------

Lung Cancer ------
Diabetes ------
Epilepsy ------
Back injury ------
Arthritis or
joint problems --------

Other Conditions/Comments:

Present Health: Have you recently experienced:

Chest Pain ____
Shortness of Breath _____
Dizziness _____
Fainting ____
Illness ____

Surgery/Hospitalization _____
Ankle/Leg Swelling _____
Joint/Muscle Pain _____
Allergies _____

Appendix C (Con't.)

List all current medications:

Do you currently smoke? Yes ____ No ____

How long have you been smoking? _____

How many do you smoke a day? _____

Have you lost or gained more than 10 pounds in the last 30 days? Yes____ No____

How much? _____

Do you currently engage in regular physical activity? Yes ___ No___

What kind? _____

How Often _____

Do you experience pain, discomfort or shortness of breath during physical activity?

If yes, explain._____

When was your last physical? _____

Have you even been advised by a medical professional not to exercise? Yes ___ No ___

If yes, explain. _____

Appendix D

ANOVA TABLES

Table D-1

Summary of the 2x3x4 repeated measures ANOVA (group x test x bout) for peak power output during repeated cycling bouts for the creatine (n=7) and placebo (n=7) groups.

Source	SS	df	MS	F	p
Group	173579.68	1	173579.68	2.37	0.150
Error 1	880292.76	12	73357.73		
Recovery Trial	7772.98	2	3886.49	2.08	0.147
Group by Recovery Trial	14.53	2	7.27	0.00	0.996
Error 2	44796.22	24	1866.61		
Cycling Bout	447079.99	3	149026.66	65.28	0.000**
Group by Cycling Bout	3337.87	3	1112.62	0.49	0.693
Error 3	82189.35	36	2283.04		
Bout by Recovery Trial	3449.30	6	574.88	0.87	0.524
Cycling Bout by Recovery Trial by Group	3420.44	6	570.07	0.86	0.529
Residual	47122.44	71	663.70		

Note. One creatine subject did not complete bout four of the 45 second recovery test.

* $p < 0.05$ ** $p < 0.01$

Table D-2

Summary of the 2x3x4 repeated measures ANOVA (group x test x bout) for mean power output during repeated cycling bouts for the creatine (n=7) and placebo (n=7) groups.

Source	SS	df	MS	F	p
Group	51012.13	1	51012.13	1.26	0.283
Error 1	484109.10	12	40342.43		
Recovery Trial	7502.36	2	3751.18	5.44	0.011*
Group by Recovery Trial	545.12	2	272.56	0.40	0.678
Error 2	16545.96	24	689.46		
Cycling Bout	367742.94	3	122580.98	117.31	0.000**
Group by Cycling Bout	955.58	3	318.63	0.30	0.822
Error 3	37617.90	36	1044.94		
Bout by Recovery Trial	3157.52	6	526.25	2.64	0.023*
Cycling Bout by Recovery Trial by Group	772.37	6	128.73	0.65	0.693
Residual	14134.66	71	199.08		

Note. One creatine subject did not complete bout four of the 45 second recovery test.

* $p < 0.05$ ** $p < 0.01$

Table D-3

Summary of the 2x3x4 repeated measures ANOVA (group x test x bout) for percent fatigue across each bout during repeated cycling bouts for the creatine (n=7) and placebo (n=7) groups.

Source	SS	df	MS	F	p
Group	1076.55	1	1076.55	1.29	0.278
Error 1	10001.72	12	833.48		
Recovery Trial	72.38	2	36.19	0.53	0.596
Group by Recovery Trial	53.46	2	26.73	0.39	0.496
Error 2	1644.31	24	68.51		
Cycling Bout	57.66	2	28.83	0.72	
Group by Exercise Bout	69.64	2	34.82	0.87	0.431
Error 3	958.27	24	39.93		
Bout by Recovery Trial	79.30	4	19.83	0.79	0.540
Cycling Bout by Recovery Trial by Group	39.67	4	9.92	0.39	0.812
Residual	1210.03	48	25.21		

Note. One creatine subject did not complete bout four of the 45 second recovery test. Percent fatigue for each bout was calculated as ((highest - lowest power output) / highest power output) X 100.

* $p < 0.05$

Table D-4

Summary of the 2x3 repeated measures ANOVA (group x test) for percent fatigue across all four cycling bouts for the creatine (n=7) and placebo (n=7) groups.

Source	SS	df	MS	F	p
Group	21.37	1	21.37	0.27	0.615
Error 1	959.30	12	79.94		
Recovery Trial	152.27	2	76.28	5.50	0.011*
Group by Recovery Trial	8.21	2	4.11	0.30	0.746
Residual	332.57	24	13.86		

Note. One creatine subject did not complete bout four of the 45 second recovery test. Percent fatigue for each bout was calculated as ((highest - lowest power output)/ highest power output) X 100.

* $p < 0.05$

Table D-5

Summary of the 2x3x4 repeated measures ANOVA (group x test x bout) for blood lactate during repeated cycling bouts for the creatine (n=7) and placebo (n=7) groups.

Source	SS	df	MS	F	p
Group	0.12	1	0.12.	0.01	0.93
Error 1	153.75	12	12.81		
Recovery Trial	2.92	2	1.46	1.40	0.27
Group by Recovery Trial	7.18	2	3.59	3.44	0.05*
Error 2	25.06	24	1.04		
Cycling Bout	1409.50	2	704.75	140.98	0.00**
Group by Cycling Bout	8.11	2	4.05	0.81	0.46
Error 3	109.98	22	5.00		
Bout by Recovery Trial	21.20	4	5.30	5.55	0.00**
Cycling Bout by Recovery Trial by Group	12.40	4	3.10	3.25	0.02
Residual	42.01	44	0.95		

Note. For one creatine subject, blood lactate was not measured pre-exercise, and post-exercise bout two.

* $p < 0.05$

** $p < 0.01$

Table D-6

One-way analysis of variance between groups for post-supplementation body weight.

Source	SS	df	MS	F	p
Group	195.00	1	195.00	0.509	0.489
Residual	4594.52	12	382.76		
Total	4789.52	13	368.43		

* $p < 0.05$

Table D-7

One-way analysis of variance between groups for post-supplementation creatinine excretion.

Source	SS	df	MS	F	p
Group	6.32	1	6.32	60.85	0.000**
Residual	1.25	12	0.10		
Total	7.56	13	0.58		

* $p < 0.05$
** $p < 0.01$

Appendix E

RAW DATA

Table E- 1

Subject raw data table.

		Wingate Test (watts)			Blood Lactate (mMol)		Heart Rate (bpm)	
subject #	condition	peak	Mean	VO_2 $ml \cdot kg^{-1} min^{-1}$	rest	max	pre-test	max
1	1	929	770	56.93	1.12	11.66	70	190
2	2	917	667	60.25	2.07	14.89	72	192
3	2	1071	799	63.19	1.92	15.32	63	196
4	2	901	709	63.53	0.92	9.83	52	185
5	1	744	578	59.35	1.90	13.38	76	187
6	2	837	690	57.71	1.08	9.07	60	190
7	2	732	567	65.15	1.44	12.98	81	207
8	2	816	577	53.31	0.97	9.14	64	192
9	1	707	587	52.11	1.08	11.83	85	202
10	1	858	666	57.81	1.61	11.62	72	192

(table continues)

		Wingate Test (watts)			Blood Lactate (mMol)		Heart Rate (bpm)	
subject #	condition	peak	Mean	VO_2 $ml \cdot kg^{-1} min^{-1}$	rest	max	pre-test	max
11	1	1053	812	62.02	1.30	15.62	60	192
12	2	934	781	63.77	1.56	10.93	59	189
13	1	1049	809	53.93	2.63	9.89	50	180
14	1	872	723	67.25	3.81	17.37	75	204

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
1	1	2	1	647	597	18.7	185	171	1.37	52.91
		2	2	587	519	25.4	192	189	15.21	52.48
		2	3	491	468	13.8	199	189		54.14
		2	4	476	436	19.7	197		18.98	55.04
		3	1	682	605	28.9	199	185	0.71	43.57
		3	2	576	531	19.1	203	190	16.46	54.08
		3	3	467	422	19.7	203	193		54.56
		3	4	502	475	13.5	206		19.69	55.07
		1	1	600	582	8.2	190	184	1.02	49.75
		1	2	545	507	18.3	195	188	15.93	54.06
		1	3	487	435	26.1	199	199		56.99

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
1		1	4	487	445	23.6	203		19.78	56.30
2	2	3	1	743	588	40.8	190	177	1.55	51.43
		3	2	592	508	29.7	192	171	16.54	56.55
		3	3	556	458	29.3	189	172		54.61
		3	4	570	480	25.6	191		18.26	46.22
		2	1	718	578	38.7	188	176	1.27	56.40
		2	2	591	496	29.6	188	173	15.79	56.62
		2	3	637	479	40.8	188	176		58.65
		2	4	531	436	30.3	189		18.74	57.32
		1	1	708	575	32.5	185	173	1.97	50.67
		1	2	617	495	35.3	186	175	14.35	54.09

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
2		1	3	618	425	44.3	185	176		54.11
		1	4	598	459	37.1	188		20.20	55.89
3	2	3	1	822	624	45.7	187	176	2.18	56.79
		3	2	762	568	42.5	191	174	18.30	59.99
		3	3	661	505	41.6	190	178		57.54
		3	4	595	463	38.7	186		21.05	58.33
		2	1	908	662	48.7	190	182	2.83	56.03
		2	2	734	538	42.9	192	182	17.76	58.98
		2	3	646	492	38.2	192	182		58.96
		2	4	603	496	29.9	189		22.20	53.08
		1	1	812	642	42.9	196	184	1.23	53.14

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
3		1	2	665	525	37.0	196	190	10.50	58.96
		1	3	581	454	35.8	198	192		57.49
		1	4	580	447	35.2	199		21.70	55.89
4	2	2	1	696	574	32.5	168	153	2.40	55.81
		2	2	599	491	34.9	179	161	14.20	60.88
		2	3	539	425	39.9	177	156		61.14
		2	4	538	434	38.1	178		17.62	62.31
		3	1	658	557	32.7	179	148	2.11	58.71
		3	2	603	489	34.8	179	151	14.03	62.03
		3	3	533	410	45.4	175	151		60.18
		3	4	542	434	33.4	176		16.24	58.44

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
4		1	1	673	565	30.6	178	162	1.28	59.86
		1	2	580	470	31.4	180	165	10.52	65.43
		1	3	511	429	34.8	179	167		62.78
		1	4	497	414	33.0	180		19.43	62.36
5	1	3	1	540	411	47.2	174	166	0.95	56.89
		3	2	366	333	20.8	181	164	16.70	58.53
		3	3	359	326	18.9	178	165		61.18
		3	4	361	328	21.3	180		19.34	57.24
		1	1	464	405	25.6	188	181	2.25	59.50

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
5		1	2	358	335	14.2	186	179	15.19	58.19
		1	3	342	311	18.1	186	179		58.98
		1	4	314	307	6.7	187		19.47	60.13
		2	1	438	415	13.2	184	169	1.38	56.49
		2	2	417	379	12.0	184	169	15.67	58.35
		2	3	398	367	13.8	184	169		57.35
		2	4	395	374	9.4	184		18.37	58.21
6	2	3	1	629	564	23.2	176	152	1.57	45.27
		3	2	587	508	29.3	178	151	15.35	52.50
		3	3	570	486	30.7	180	153		50.57
		3	4	579	455	42.8	180		20.32	51.35

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
6		1	1	618	554	22.5	178	166	0.88	45.35
		1	2	531	479	26.9	181	166	14.13	50.83
		1	3	513	424	36.3	181	169		47.90
		1	4	467	393	31.0	181		18.80	49.74
		2	1	596	550	18.1	181	168	1.32	45.86
		2	2	567	506	28.0	183	160	15.98	55.54
	2	2	3	544	458	33.3	184	161		54.77
		2	4	527	440	33.8	184		19.70	53.11
7	2	3	1	452	425	13.9	193	174		47.63
		3	2	424	394	18.9	198	179		55.83
		3	3	393	363	15.0	199	184		57.69

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
7		3	4	389	355	21.1	202		15.98	57.85
		1	1	473	439	19.5	200	185		51.65
		1	2	416	373	22.1	204	198		58.84
		1	3	371	306	34.0	203	195		52.45
		1	4						16.84	
		2	1	414	391	11.8	193	177		50.89
		2	2	373	354	11.3	197	183		53.89
		2	3	365	337	11.2	198	183		54.47
		2	4	382	359	9.9	200		16.60	50.17
8	2	1	1	621	455	42.0	180	168	2.91	48.52
		1	2	540	399	44.3	187	171	11.26	53.60

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
8		1	3	547	407	45.3	187	170		58.38
		1	4	528	381	46.0	195		19.12	52.85
		3	1	603	440	47.3	180	160	1.84	48.72
		3	2	540	402	44.6	185	158	12.51	53.80
		3	3	529	385	44.2	189	168		53.87
		3	4	516	381	46.7	193		16.86	50.34
		2	1	596	455	42.6	177	160	1.67	48.81
		2	2	561	394	47.1	184	165	13.75	52.18
		2	3	517	380	45.3	187	175		54.40
		2	4	521	369	45.5	193		17.94	50.62
9	1	1	1	592	461	47.0	192	180	1.33	54.40

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
9		1	2	493	346	46.0	194	180	17.3	57.44
		1	3	450	336	39.0	189	176		57.92
		1	4	454	300	51.0	192		19.65	57.02
		2	1	522	469	28.0	186	170	1.57	46.83
		2	2	458	393	35.0	190	176	14.45	55.53
		2	3	433	343	40.0	188	174		57.28
		2	4	454	354	39.0	193		17.76	56.50
		3	1	504	475	20.0	186	168	1.49	48.79
		3	2	482	424	32.0	184	167	14.52	54.75
		3	3	484	379	41.0	189	171		54.33
		3	4	484	352	48.0	193		18.74	50.08

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
10	1	2	1	633	518	37.6	191	179	1.75	54.60
		2	2	526	393	40.3	189	166	17.33	55.07
		2	3	515	399	39.2	184	168		55.16
		2	4	492	383	37.8	193		18.56	52.91
		1	1	607	509	36.1	193	180	1.87	54.16
		1	2	495	403	36.4	188	178	16.88	58.52
		1	3	461	376	33.8	188	174		58.17
		1	4	430	356	31.4	188		18.47	55.72
		3	1	644	524	35.6	190	172	2.79	57.52
		3	2	549	432	35.9	187	162	14.35	59.99
		3	3	531	417	40.5	184	164		57.21

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
10		3	4	514	422	32.3	184		16.23	55.20
11	1	1	1	666	588	23.6	189	178	2.55	50.04
		1	2	536	486	20.1	191	179	13.4	55.64
		1	3	531	467	22.0	192	179		61.05
		1	4	546	463	26.4	195		17.75	62.19
		3	1	729	584	35.5	192	170	1.30	55.69
		3	2	642	483	42.5	195	173	14.44	61.23
		3	3	541	448	33.8	195	177		59.60
		3	4	549	442	40.1	196		17.09	55.40
		2	1	683	572	30.7	190	172	1.86	52.82
		2	2	607	482	37.7	190	171	12.26	59.04

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
11		2	3	551	449	34.8	191	174		60.34
		2	4	650	466	39.4	195		19.72	64.90
12	2	2	1	735	623	29.1	180	150	1.40	50.99
		2	2	649	542	32.8	181	156	11.31	58.02
		2	3	604	521	30.3	181	162		57.00
		2	4	592	488	40.4	182		17.66	56.14
		1	1	754	606	34.2	185	167	1.46	53.09
		1	2	648	527	33.5	187	169	10.63	57.82
		1	3	578	488	28.7	186	160		58.11
		1	4	557	480	27.3	184		16.91	55.28

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
12	2	3	1	699	618	23.9	184	142	1.87	55.44
		3	2	685	582	25.5	185	146	11.23	57.53
		3	3	672	557	34.7	187	147		58.87
		3	4	575	507	28.2	184		15.73	56.82
13	1	1	1	737	562	40.4	180	169	1.96	51.82
		1	2	569	440	36.9	178	171	9.35	53.15
		1	3	538	385	41.4	180	165		52.65
		1	4	533	392	35.5	180		13.84	48.67
		2	1	667	547	32.1	176	143	1.93	45.00
		2	2	546	446	32.1	173	144	10.37	48.52
		2	3	446	392	23.3	173	147		48.13

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
13		2	4	461	374	29.1	170		13.79	47.49
		3	1	687	525	39.7	178	160	1.59	49.37
		3	2	530	405	37.9	179	157	11.75	50.55
		3	3	501	396	32.3	174	159		48.71
		3	4	488	376	33.2	176		12.27	42.70
14	1	1	1	564	504	16.5	189	177	2.53	59.19
		1	2	488	467	9.2	190	179	12.37	61.53
		1	3	455	433	15.6	192	182		63.49
		1	4	465	429	15.9	194		16.93	64.80

(table continues)

				Power Output (watts)			Heart Rate (bpm)			
subject #	condition	trial	bout	peak	mean	% fatigue	max	recovery	lactate mMol	VO_2 $ml \cdot kg^{-1} min^{-1}$
14		2	1	525	505	8.8	185	168	2.31	56.65
		2	2	482	463	9.3	185	168	14.31	62.47
		2	3	483	446	16.6	186	173		64.43
		2	4	465	425	15.1	185		17.49	64.01
		3	1	520	491	10.4	189	164	1.62	55.53
		3	2	494	477	6.9	189	167	11.57	62.26
		3	3	466	446	10.9	191	172		64.65
		3	4	480	453	11.5	194		16.31	66.26

Note. Conditions are: 1- Placebo; 2- Creatine.