The Effects of Creatine Monohydrate Loading on Anaerobic Performance and One-Repetition Maximum Strength

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[1]*Department of Kinesiology, School of Allied Health, Western New Mexico University, Silver City, New Mexico;* [2]*Department of Nutrition and Health Sciences, University of Nebraska-Lincoln, Lincoln, Nebraska;* [3]*Department of Health & Physical Education, University of Wisconsin-Platteville, Platteville, Wisconsin;* [4]*Department of Exercise and Sport Science, College of Science and Health, University of Wisconsin-La Crosse, La Crosse, Wisconsin; and* [5]*Department of Oral Biology, College of Dentistry, University of Nebraska Medical Center, Lincoln, Nebraska*

Abstract

Zuniga, JM, Housh, TJ, Camic, CL, Hendrix, CR, Mielke, M, Johnson, GO, Housh, DJ, and Schmidt, RJ. The effects of creatine monohydrate loading on anaerobic performance and one-repetition maximum strength. *J Strength Cond Res* 26(6): 1651–1656, 2012—The purpose of this study was to examine the effects of 7 days of supplementation with 20 g·d^{-1} of creatine monohydrate (CM) on mean power (MP) and peak power (PP) from the Wingate anaerobic test (WAnT), body weight (BW), 1-repetition maximum (1RM) bilateral leg extension (LE) strength, and 1RM bench press (BP) strength. This study used a randomized, double-blind, placebo-controlled design. Twenty-two men (mean ± *SD*: age = 22.1 ± 2.0 years; height = 178.0 ± 5.8 cm; body weight [BW] = 77.6 ± 7.6 kg) were randomly assigned to either a supplement (SUPP; n = 10) or placebo (PLAC; n = 12) group. The SUPP group ingested 20 g·d^{-1} of CM powder for 7 days, whereas the PLAC ingested 20 g·d^{-1} of maltodextrin powder. Measurements for the PLAC and SUPP groups included BW, PP, and MP from two 30-second WAnTs (separated by 7 minutes), and 1RM strength for LE and BP. Testing was conducted before (PRE) and after (POST) 7 days of ingesting either the supplement or placebo. The results of this study indicated that there was a significant ($p \leq 0.05$) increase from PRE to POST testing in MP for the SUPP group (5.4%) but not for the PLAC group (−0.3%). There were no between-group differences, however, for 1RM LE and 1RM BP strength. Furthermore, there were no changes in PP or BW for either group. The findings of this study indicated that loading with 20 g·d^{-1} of CM for 7 days increased MP (5.4% increase) from the WAnT, but it had no effect on strength (1RM LE and 1RM BP), PP, or BW.

Key Words short-term creatine supplementation, Wingate anaerobic test performance, upper body strength, lower body strength

Introduction

During short-duration, high-intensity exercise, the adenosine triphosphate (ATP)-phosphocreatine (PCr) system is the predominant supplier of ATP for the working muscle (16). Creatine monohydrate (CM) has been used to increase intramuscular PCr stores for ATP rephosphorylation to delay the onset of muscular fatigue and increase performance (22). Other potential mechanisms for the ergogenic effect of CM supplementation involve the buffering of hydrogen ions during the creatine kinase reaction, stimulation of phosphofructokinase (PFK) activity, and an enhanced capacity for high-energy phosphate diffusion between the mitochondria and the myosin heads (4).

Creatine monohydrate supplementation has been used by athletes and nonathletes to enhance exercise performance and increase muscular strength (16). A number of studies have demonstrated the benefits of CM loading on high-intensity cycle ergometry (5,7,22). For example, Birch et al. (5) found that loading with 20 g·d^{-1} of CM for 5 days increased the mean power (MP) and total work performed by 6% during 30-second isokinetic cycling tests. Similarly, Casey et al. (7) reported a 4% increase in the total work performed after 20 g·d^{-1} of CM for 5 days during 30-second isokinetic cycling tests. Furthermore, Dawson et al. (8) reported that loading with 20 g·d^{-1} of CM for 5 days increased peak power (PP; 4.6%) and the total work performed (4.5%) during repeated high-intensity cycling sprints. There are conflicting results, however, regarding the effects of CM loading in muscular strength (11,16,23). For example, Izquierdo et al.

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(16) found that loading with 20 g·d^{-1} of CM for 5 days increased 1-repetition maximum (1RM) squat strength with no increase in 1RM bench press (BP). Furthermore, loading with 20 g·d^{-1} of CM for 2 days increased concentric, isokinetic leg extension (LE) peak torque (23), but 5 days of supplementation (20 g·d^{-1}) did not (11).

It has been suggested that loading with CM may have performance-enhancing benefits without exercise training. For example, van Loon et al. (22) investigated the effects of short-term CM supplementation on body composition and substrate use, and sprint and endurance performance in untrained subjects. It was reported that the subjects in the CM supplementation group, but not those in the placebo group, experienced significant improvements in performance during repeated high-intensity cycle ergometry, and increased body weight (BW), total muscle creatine content, and intramuscular PCr content after ingesting 20 g·d^{-1} of CM for 5 days (22). There are conflicting findings, however, regarding increases in BW after short-term CM supplementation (8,10,13,19). For example, Dawson et al. (8) reported no significant changes in the BW for a sample of male subjects randomly assigned to either a supplement (20 g·d^{-1} of CM for 5 days) or placebo group. More recently, Fukuda et al. (10) found no significant changes in BW for a sample of male ($n = 12$) and female ($n = 12$) subjects after loading with 20 g·d^{-1} of creatine citrate for 5 days. Thus, it is unclear if the ingestion of 20 g·d^{-1} of CM for 7 days, in the absence of an exercise intervention, would increase the performance in the Wingate anaerobic test (WAnT), 1RM strength, or BW. Therefore, the purpose of this study was to examine the effects of 7 days of supplementation with 20 g·d^{-1} of CM on MP and PP from the WAnT, BW, 1RM bilateral LE strength, and 1RM BP strength. Based on the results of previous studies (5,7,8,10,11,13,16,19,22), we hypothesized that loading with 20 g·d^{-1} of CM for 7 days would result in increases in MP and PP from the WAnT independent of changes in BW. In addition, loading with CM would have no effect on the 1RM strength for LE or BP.

Methods

Experimental Approach to the Problem

This study used a randomized, double-blind, placebo-controlled design. The subjects were randomly assigned to either a supplement (SUPP; $n = 10$) or placebo (PLAC; $n = 12$) group. The SUPP group ingested 20 g·d^{-1} of CM powder for 7 days, whereas the PLAC ingested 20 g·d^{-1} of maltodextrin powder. The PLAC was designed by the manufacturer (General Nutrition Corporation, Pittsburgh, PA, USA) such that each dose (i.e., 1 packet) had the same volume, taste, and color as the SUPP did. The subjects mixed their own drink (i.e., SUPP or PLAC) from a packet that had the premeasured volume of powder needed for 1 serving. Both the SUPP and PLAC drinks were mixed with 12 oz. of water. Measurements for the PLAC and SUPP groups included BW, MP, and PP from two 30-second WAnTs (separated by 7 minutes), and 1RM dynamic constant external resistance (DCER) strength for LE and BP. Testing was conducted before (PRE) and after (POST) 7 days of ingesting either the supplement or placebo. All the subjects performed the PRE and POST tests at about the same time of the day (±2 hours). No dietary restrictions were enforced during the course of this study, and the subjects were encouraged to continue with their normal exercise and dietary habits. Furthermore, each subject completed a 3-day food log during the supplementation period to monitor the caloric (kilocalories), protein (grams), carbohydrates (grams), and fat (grams) intake.

Subjects

Twenty-two men (mean ± *SD*: age = 22.1 ± 2.0 years; BW = 77.6 ± 7.6 kg; height = 178.0 ± 5.8 cm) volunteered

Table 1. Body weight, mean power, peak power, and strength values (mean ± *SD*) PRE and POST ingesting either 20 g·d^{-1} of creatine monohydrate (SUPP) or 20 g·d^{-1} maltodextrin powder (PLAC).*

	PRE		POST	
	SUPP	PLAC	SUPP	PLAC
Body weight (kg)	75.04 ± 7.75	79.83 ± 6.27	75.07 ± 7.78	79.73 ± 6.44
Peak power (W)	785.80 ± 77.47	728.63 ± 114.31	806.65 ± 81.07	738.08 ± 96.84
Mean power (W)†	624.55 ± 73.84	591.75 ± 98.09	658.25 ± 79.96	590.08 ± 82.01
1RM LE (kg)	115.44 ± 18.66	126.82 ± 20.91	126.55 ± 19.71	137.40 ± 18.03
1RM BP (kg)	91.40 ± 23.66	92.61 ± 25.78	93.44 ± 24.60	93.93 ± 24.05

*PRE = before 7 days; POST = after 7 days; SUPP = supplement; PLAC = placebo; 1RM = 1 repetition maximum; LE = leg extension; BP = bench press.

†There was a significant ($p < 0.05$) increase from PRE to POST testing in the mean power for the SUPP group but not for the PLAC group. There were PRE to POST increases for 1RM LE and 1RM BP strength for the PLAC and SUPP groups but no differences between the groups. There were no changes PRE to POST or differences between groups (PLAC and SUPP) for peak power or body weight.

Table 2. Caloric (kilocalories) and macronutrients (grams of protein, carbohydrates, and fat) intake (mean ± *SD*) for the SUPP and PLAC groups.*†

	SUPP	PLAC
Energy (kcal)	2,674.87 ± 879.65	2,531.89 ± 519.56
Protein (g)	117.34 ± 47.68	114.59 ± 37.10
Carbohydrates (g)	352.45 ± 62.00	302.94 ± 51.69
Fat (g)	83.49 ± 25.75	87.35 ± 34.08

*SUPP = supplement; PLAC = placebo.
†There were no significant ($p > 0.05$) differences for the caloric and macronutrient intake between the SUPP and PLAC groups.

for this investigation. The subjects were untrained in resistance training and engaged in not >4 hours of recreational activity per week. In addition, the subjects did not report or exhibit (a) a history of medical or surgical events that could significantly affect the study outcome, including cardiovascular disease or metabolic, renal, hepatic, or musculoskeletal disorders; (b) use of any medication; (c) use of nutritional supplements; or (d) participation in another clinical trial or ingestion of another investigational product within 30 days before screening and enrollment. The study was approved by the University of Nebraska-Lincoln Institutional Review Board for Human Subjects, and all the subjects completed a health history questionnaire and signed a written informed consent before testing.

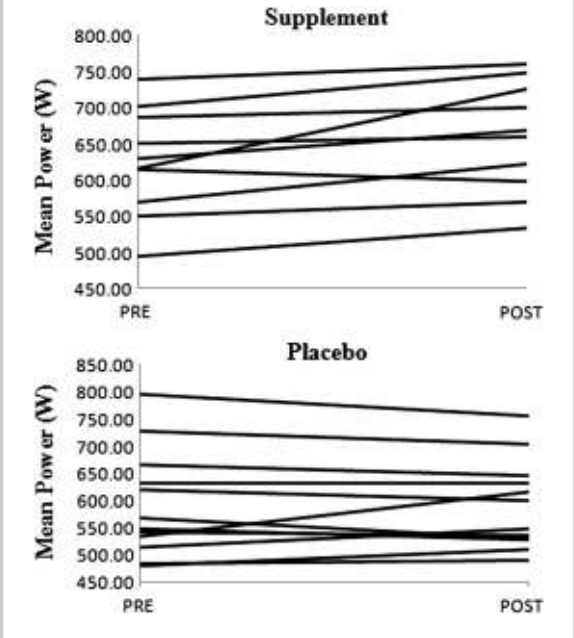

Figure 1. The upper graph shows the individual results for the mean power for the supplement group. The lower graph shows the individual results for the mean power for the placebo group.

Testing

Anaerobic Performance. To assess anaerobic performance, the subjects performed 2 WAnTs on a bicycle ergometer (Monarch 818 E; Quinton Instruments, Seattle, WA, USA) separated by 7 minutes. Before the tests, the seat was adjusted to allow for near full extension of the legs while pedaling, and toe clips with straps were used to prevent the feet from slipping off the pedals. The subjects warmed up by cycling for 4 minutes against a load of 0.5 kg. Before the start of the first test, the subjects were instructed to pedal as fast as possible from the beginning and attempt to maintain maximum pedal speed throughout the 30-second test. At the command to go, the subjects began pedaling as fast as possible against a low resistance that was increased to 7.5% of the subject's BW within 2–3 seconds (2). When this load was reached, an optical sensor (OptoSensor 2000; Linear System Design, Delray Beach, FL, USA) interface with a personal computer (Gateway 2000, Irvine, CA, USA) counted the number of flywheel revolutions every 1.0 second. Computer software (SMI Power, Linear System Design, SMI, St. Cloud, MN, USA) calculated PP (the highest power output during any 5-second period) and MP (the average power output during the 30-second test) (2). The PP and MP values from the first and second WAnTs were then averaged. Between the first and second WAnTs, each subject performed an active cooldown pedaling against a resistance of 0.5 kg for 3 minutes, followed by a passive recovery period of 4 minutes. The test-retest reliability data from our laboratory for MP and PP indicated that for adult male subjects ($n = 20$) measured 2–7 days apart, the intraclass correlations (R) were 0.976 and 0.960, respectively, with no significant ($p > 0.05$) mean differences between test and retest values.

Muscular Strength. The subjects performed tests to determine 1RM DCER muscular strength for LE and BP exercises. The LE exercises were performed on a plate-loaded LE resistance training machine (Body-Solid, Model CEC340; Forest Park, IL, USA). Each subject sat with his back flat against the back rest and was instructed to hold tightly to the handles of the device. The back rest was adjusted to align the anatomical axes of both knees with the mechanical axis of the machine. The subject's legs were strapped to shin pads that were attached to the lever arm of the machine. The distance between the shin pads and the axis of rotation of the lever arm was fixed and not adjustable. The positioning of each subject, however, was consistent across all tests. The

Table 3. Statistical estimates for the dependent variables in this study.*†

Variable	*p*	*F*	Effect size	Observed power
Body weight (kg)				
Group × time interaction	0.76	0.10	0.01	0.06
Group main effect	0.13	2.47	0.11	0.32
Time main effect	0.84	0.04	0.00	0.05
Peak power (W)				
Group × time interaction	0.59	0.29	0.02	0.08
Group main effect	0.12	2.56	0.11	0.33
Time main effect	0.16	2.12	0.10	0.28
Mean power (W)				
Group × time interaction	0.03†	5.81	0.23	0.63
Group main effect	0.16	2.05	0.09	0.27
Time main effect	0.04†	4.76	0.19	0.55
1RM leg extension (kg)				
Group × time interaction	0.92	0.01	0.01	0.05
Group main effect	0.17	1.98	0.09	0.27
Time main effect	0.01†	18.23	0.47	0.98
1RM bench press (kg)				
Group × time interaction	0.65	0.211	0.01	0.07
Group main effect	0.94	0.00	0.00	0.05
Time main effect	0.04†	4.63	0.18	0.54

*1RM = 1 repetition maximum.
†Significant ($p < 0.05$) Group (supplement and placebo) × Time (PRE and POST) interaction for mean power and significant time main effects for mean power, 1RM leg extension, and bench press strength for the supplement and placebo groups.

BP exercises were performed on a standard free-weight bench (Body Power, Williamsburg, VA, USA) with an Olympic bar. After receiving a lift-off from a spotter, the subjects lowered the bar to their chest, paused briefly, and then pressed the bar to full extension of the forearms. For both the LE and BP exercises, 1RM DCER strength was determined by applying progressively heavier loads until the subject could not complete a repetition through the full extension of the legs. Additional trials were performed with lighter loads until the 1RM was determined within 2.27 kg, and this was usually achieved within 5 trials. Two minutes of rest was allowed between all the trials, 2000). The test-retest reliability data from our laboratory for 1RM LE and 1RM BP indicated that for adults male subjects ($n = 20$) measured 2–7 days apart, the intraclass correlations (R) were 0.899 and 0.996, respectively, with no significant ($p > 0.05$) mean differences between test and retest values.

Statistical Analyses

Five separate 2-way mixed factorial analyses of variance (ANOVAs; 2 × 2; time [PRE and POST] × group [SUPP and PLAC]) were used to analyze the BW, PP, MP, 1RM LE, and 1RM BP data. When appropriate, follow-up analyses included paired sample *t*-tests. In addition, the caloric (kilocalories) and macronutrients (grams of protein, carbohydrates, and fat) intake for the SUPP and PLAC groups were compared using independent *t*-tests. An alpha of $p \leq 0.05$ was considered statistically significant for all comparisons.

Results

The results of the statistical analyses for BW, PP, MP, 1RM LE, and 1RM BP values are presented in Table 1. The results of the comparisons for the caloric (kilocalories) and macronutrients (grams of protein, carbohydrates, and fat) intake between the SUPP and PLAC groups are presented in Table 2. For MP, the 2 × 2 mixed factorial ANOVA (time [PRE and POST] × group [SUPP and PLAC]) resulted in a significant ($p < 0.05$) time × group interaction. A follow-up dependent *t*-test indicated that there was a significant increase from PRE (SUPP: 624.55 ± 73.84 W and PLAC: 591.75 ± 98.09 W) to POST (SUPP: 658.25 ± 76.96 W and PLAC: 590.08 ± 82.01 W) testing for the SUPP group (5.4%) but not for the PLAC group (Table 1). Figure 1 shows the individual results for MP values for the PLAC and SUPP groups (−0.3%). For the PLAC group, 3 subjects had greater MP values for the POST than for the PRE tests, 7 subjects had lower MP values for the POST than for the PRE tests, and for 2 subjects, the MP values were the same for the POST and PRE tests. For the SUPP group, 9 subjects had greater MP values for the POST than PRE tests, and 1 subject had lower MP for the POST test than for the PRE test (Figure 1). There was no significant group × time interaction or main effect for group for 1RM LE, 1RM BP, PP, and BW (Table 1). There was a significant main effect for time, however, for 1RM LE and 1RM BP. In addition, there were no significant differences between the PLAC and SUPP groups for caloric (kilocalories) and macronutrients (grams of protein, carbohydrates, and fat) intake (Table 2). The post hoc power analyses (Table 3) indicated that values ranged from 0.05 to 0.98 for all group × time interactions (0.05–0.63), main effects for group (0.05–0.33), and main effects for time (0.05–0.98).

Discussion

The findings of this study indicated that loading with 20 $g \cdot d^{-1}$ of CM for 7 days increased MP (5.4%) from the WAnT, but it

had no effect on strength (1RM LE and 1RM BP), PP, or BW. The MP from the WAnT reflects the capacities of the ATP-PCr and glycolytic metabolic systems (3) and, therefore, the present findings suggest that the CM supplementation resulted in an increase in the capacity to anaerobically produce ATP. These findings were similar to those of Birch et al. (5) who found that ingesting 20 $g \cdot d^{-1}$ of CM for 5 days, resulted in 6% increases in MP and total work performed in the first 2 of 3 maximal 30-second isokinetic cycling tests. Furthermore, it was reported (5) that the creatine supplementation lowered the plasma concentration of ammonia and enhanced muscle ATP turnover. Using similar supplementation (20 $g \cdot d^{-1}$ of CM for 5 days) and cycling (2 × 30-second isokinetic cycling tests) protocols, Casey et al. (7) reported a 4% increase in the total work performed. Furthermore, the increase in total work was correlated with the intramuscular concentration of creatine ($r = 0.71$), and there was a 30% reduction in the decline of muscle ATP concentration after the isokinetic cycling tests (7). The authors (7) concluded that there was an attenuation of ATP degradation because of the increased intramuscular concentration of PCr. Previous studies (9,18), however, have reported no ergogenic effect from loading with 20 $g \cdot d^{-1}$ of CM during high-intensity cycling exercise. For example, Odland et al. (18) reported no significant changes or between-group differences in PP or MP for SUPP (20 $g \cdot d^{-1}$ of CM), placebo, and control groups after 3 days of supplementation. It was concluded (18) that 3 days of loading did not result in a significant increase in intramuscular concentrations of creatine and PCr, and thus, there were no increase in PP and MP from the WAnT. In partial agreement with Odland et al. (18), this study found that there was no change in PP for the SUPP or PLAC groups, but there was a 5.4% increase in MP for the SUPP group.

Creatine supplementation can act through multiple mechanisms (4). For example, for activities with durations between 10 seconds and 2 minutes (i.e., MP), creatine can reduce pH changes from acidosis by using the hydrogen ions during the creatine kinase reaction and the rephosphorylation of ADP to ATP (4). Furthermore, the declining levels of intramuscular PCr because of rephosphorylation of ADP during high-intensity exercise can stimulate PFK activity and, thus, increase the rate of ATP production from anaerobic glycolysis (4). For short-duration, high-intensity activities of <10 seconds (i.e., PP), however, ATP production is mainly because of the rapid rephosphorylation of ADP to ATP by the creatine kinase reaction (4,20). Our results showed that there were no significant differences between the SUPP (PRE: 785.80 ± 77.47 W and POST: 806.65 ± 81.07 W) and PLAC (PRE: 728.63 ± 114.31 W and POST: 738.08 ± 96.84 W) groups for PP before or after the ingestion of 20 g of CM for 7 days (Table 1). For MP, however, only the SUPP (PRE: 624.55 ± 73.84 W and POST: 658.25 ± 79.96 W) group increased (5.4%), whereas the PLAC group remained unchanged (PRE: 591.75 ± 98.09 W and POST: 590.08 ± 82.01 W) (Table 1). Thus, it is possible that the increase in MP for the SUPP group found in this study may have resulted from an increase in ATP production from anaerobic glycolysis, because of the buffering effect of creatine (4).

Like this study, a number of investigations (21) have shown no effect of CM loading on 1RM strength. For example, Hamilton et al. (14) reported no significant changes or between-group differences in 1RM strength for elbow flexion (SUPP group: PRE = 36.2 ± 1.8 N·m, POST = 37.8 ± 1.7 N·m and PLAC group: PRE = 34.4 ± 2.5 N·m, POST = 35.0 ± 2.6 N·m) or shoulder internal rotation (SUPP group: PRE = 34.1 ± 1.6 N·m, POST = 35.6 ± 1.5 N·m and PLAC group: PRE = 35.4 ± 2.1 N·m, POST = 36.7 ± 2.1 N·m) after 7 days of ingesting 25 $g \cdot d^{-1}$ of CM or a placebo. In addition, Syrotuik et al. (21) found no significant changes or between-group differences in 1RM BP (SUPP group: PRE = 90.6 ± 7.1 kg, POST = 93.2 ± 7.7 kg and PLAC group: PRE = 87.5 ± 7.1 kg, POST = 89.4 ± 6.9 kg) or 1RM leg press strength (SUPP group: PRE = 308.1 ± 37.4 kg, POST = 321.7 ± 34.8 kg and PLAC group: PRE = 298.6 ± 33.5 kg, POST = 298.5 ± 37.0 kg) after 5 days of ingesting about 21 $g \cdot d^{-1}$ (0.3 $g \cdot kg^{-1}$ BW) of CM or a placebo. These studies (14,21) concluded that the CM supplementation did not increase 1RM strength measures for the upper or lower body. Volek et al. (24), however, found a significant increase in 1RM BP for a group that ingested 25 $g \cdot d^{-1}$ of CM for 7 days, with no increase for the placebo group. The results of this study indicated that there were PRE to POST increases in 1RM LE and 1RM BP strength for both PLAC and SUPP groups but no difference between the groups (Table 1). Thus, the present findings were consistent with those of previous investigations (14,21) that have shown no effect of CM loading on the 1RM strength for the upper or lower body.

It has been reported (12) that the ergogenic effects of creatine supplementation may be attributable, in part, to increases in BW. There are a number of studies (1,10,17), however, that have reported that the ergogenic effects of creatine loading did not coincide with the changes in BW. For example, Fukuda et al. (10) reported a 23% increase in anaerobic running capacity (PRE = 0.245 ± 0.069 km and POST = 0.302 ± 0.091 km) after creatine loading (5 $g \cdot d^{-1}$ for 5 days), with no changes in BW (PRE = 77.0 ± 9.1 kg and POST = 77.6 ± 9.4 kg). Furthermore, there is conflicting evidence regarding changes in BW after loading with CM (8,13,19). For example, van Loon et al. (22) found a significant mean (±*SD*) increase in BW of 1.2 kg (±0.2 kg) after supplementation with 20 $g \cdot d^{-1}$ of CM for 5 days. The authors attributed these findings to water retention. In contrast, many investigations (8,10,13,19) have reported no changes in BW after ingesting 18.75 to 21 $g \cdot d^{-1}$ of CM for 5–9 days. Thus, in agreement with these previous findings (8,10,13,19), this study showed no significant change in the BW for the SUPP group (Table 1) after a loading phase of CM (20 $g \cdot d^{-1}$ for 7 days).

A possible limitation of this study was the sample size used for the SUPP ($n = 10$) and PLAC ($n = 12$) groups. As shown in Table 3, the post hoc power analyzes values ranged from 0.05 to 0.98. The number of subjects used by this study, however,

was comparable with those of previous studies (6,15) that have examined the effects of creatine supplementation on anaerobic performance, muscular strength, and BW.

In summary, the findings of the present investigation showed that 7 days of CM (20 $g \cdot d^{-1}$) supplementation resulted in a 5.4% increase ($p < 0.05$) in MP from the WAnT but had no effect on PP. The increase in MP for the SUPP group may have resulted from an increase in ATP production from anaerobic glycolysis, because of the buffering effect of creatine. Furthermore, in agreement with previous investigations, this study showed no change in the BW after loading with CM or differences between the SUPP and PLAC groups for 1RM LE and 1RM BP strength.

Practical Applications

The results of this study indicated that loading with 20 $g \cdot d^{-1}$ of CM for 7 days increased anaerobic capacity (i.e., MP) during high-intensity exercise. Furthermore, the ergogenic effect of CM on MP was independent of changes in PP or BW. In addition, the CM supplementation in this study had no effect on the 1RM strength for the upper or lower body. These findings supported the hypothesis that the buffering effect of creatine may play an important role in the ergogenic effect of a loading phase with CM. Thus, the present findings indicated that 7 days of loading with CM (20 $g \cdot d^{-1}$) can have an ergogenic effect on repeated, high-intensity activities lasting approximately 30 seconds but does not affect muscular strength or BW.

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References

1. Arciero, PJ, Hannibal, NS III, Nindl, BC, Gentile, CL, Hamed, J, and Vukovich, MD. Comparison of creatine ingestion and resistance training on energy expenditure and limb blood flow. *Metabolism* 50: 1429–1434, 2001.
2. Bar-Or, O. A new anaerobic capacity test: Characteristics and applications. In: *The 21st World Congress in Sports Medicine*. Brasilia, Brazil: University Press, 1978.
3. Bar-Or, O. The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Med* 4: 381–394, 1987.
4. Bemben, MG and Lamont, HS. Creatine supplementation and exercise performance: Recent findings. *Sports Med* 35: 107–125, 2005.
5. Birch, R, Noble, D, and Greenhaff, PL. The influence of dietary creatine supplementation on performance during repeated bouts of maximal isokinetic cycling in man. *Eur J Appl Physiol Occup Physiol* 69: 268–276, 1994.
6. Camic, CL, Hendrix, CR, Housh, TJ, Zuniga, JM, Mielke, M, Johnson, GO, Schmidt, RJ, and Housh, DJ. The effects of polyethylene glycosylated creatine supplementation on muscular strength and power. *J Strength Cond Res* 24: 3343–3351, 2010.
7. Casey, A, Constantin-Teodosiu, D, Howell, S, Hultman, E, and Greenhaff, PL. Creatine ingestion favorably affects performance and muscle metabolism during maximal exercise in humans. *Am J Physiol* 271: E31–E37, 1996.
8. Dawson, B, Cutler, M, Moody, A, Lawrence, S, Goodman, C, and Randall, N. Effects of oral creatine loading on single and repeated maximal short sprints. *Aust J Sci Med Sport* 27: 56–61, 1995.
9. Deutekom, M, Beltman, JG, de Ruiter, CJ, de Koning, JJ, and de Haan, A. No acute effects of short-term creatine supplementation on muscle properties and sprint performance. *Eur J Appl Physiol* 82: 223–229, 2000.
10. Fukuda, DH, Smith, AE, Kendall, KL, Dwyer, TR, Kerksick, CM, Beck, TW, Cramer, JT, and Stout, JR. The effects of creatine loading and gender on anaerobic running capacity. *J Strength Cond Res* 24: 1826–1833,2010.
11. Gilliam, JD, Hohzorn, C, Martin, D, and Trimble, MH. Effect of oral creatine supplementation on isokinetic torque production. *Med Sci Sports Exerc* 32: 993–996, 2000.
12. Green, JM, McLester, JR, Smith, JE, and Mansfield, ER. The effects of creatine supplementation on repeated upper- and lower-body Wingate performance. *J Strength Cond Res* 15: 36–41, 2001.
13. Grindstaff, PD, Kreider, R, Bishop, R, Wilson, M, Wood, L, Alexander, C, and Almada, A. Effects of creatine supplementation on repetitive sprint performance and body composition in competitive swimmers. *Int J Sport Nutr* 7: 330–346, 1997.
14. Hamilton, KL, Meyers, MC, Skelly, WA, and Marley, RJ. Oral creatine supplementation and upper extremity anaerobic response in females. *Int J Sport Nutr Exerc Metab* 10: 277–289, 2000.
15. Herda, TJ, Beck, TW, Ryan, ED, Smith, AE, Walter, AA, Hartman, MJ, Stout, JR, and Cramer, JT. Effects of creatine monohydrate and polyethylene glycosylated creatine supplementation on muscular strength, endurance, and power output. *J Strength Cond Res* 23: 818–826, 2009.
16. Izquierdo, M, Ibanez, J, Gonzalez-Badillo, JJ, and Gorostiaga, EM. Effects of creatine supplementation on muscle power, endurance, and sprint performance. *Med Sci Sports Exerc* 34: 332–343, 2002.
17. Kocak, S and Karli, U. Effects of high dose oral creatine supplementation on anaerobic capacity of elite wrestlers. *J Sports Med Phys Fitness* 43: 488–492, 2003.
18. Odland, LM, MacDougall, JD, Tarnopolsky, MA, Elorriaga, A, and Borgmann, A. Effect of oral creatine supplementation on muscle [PCr] and short-term maximum power output. *Med Sci Sports Exerc* 29: 216–219, 1997.
19. Prevost, MC, Nelson, AG, and Morris, GS. Creatine supplementation enhances intermittent work performance. *Res Q Exerc Sport* 68: 233–240, 1997.
20. Smith, JC and Hill, DW. Contribution of energy systems during a Wingate power test. *Br J Sports Med* 25: 196–199, 1991.
21. Syrotuik, DG, Bell, GJ, Burnham, R, Sim, LL, Calbert, RA, and Maclean, IN. Absolute and relative strength performance following creatine monohydrate supplementation combined with periodized resistance training. *J Strength Cond Res* 14: 182–190, 2000.
22. van Loon, LJ, Oosterlaar, AM, Hartgens, F, Hesselink, MK, Snow, RJ, and Wagenmakers, AJ. Effects of creatine loading and prolonged creatine supplementation on body composition, fuel selection, sprint and endurance performance in humans. *Clin Sci (Lond)* 104: 153–162, 2003.
23. Vandenberghe, K, Van Hecke, P, Van Leemputte, M, Vanstapel, F, and Hespel, P. Phosphocreatine resynthesis is not affected by creatine loading. *Med Sci Sports Exerc* 31: 236–242, 1999.
24. Volek, JS, Kraemer, WJ, Bush, JA, Boetes, M, Incledon, T, Clark, KL, and Lynch, JM. Creatine supplementation enhances muscular performance during high-intensity resistance exercise. *J Am Diet Assoc* 97: 765–770, 1997.