

The Effects of Creatine Supplementation on Anaerobic Working Capacity

JEFFREY R. STOUT,¹ JOAN M. ECKERSON,¹ TERRY J. HOUSH,² AND KYLE T. EBERSOLE²

¹Exercise Science Department, Creighton University, Omaha, Nebraska 68178; ²Center for Youth Fitness and Sports Research, Department of Health and Human Performance, University of Nebraska-Lincoln, Lincoln, Nebraska 68588-0229.

ABSTRACT

Anaerobic working capacity (AWC) estimated from the critical power test provides a theoretically and experimentally valid estimate of work capacity associated with muscle energy reserves adenosine triphosphate and phosphocreatine. Creatine monohydrate (CM) supplementation has been shown to increase phosphocreatine stores in skeletal muscle and, in theory, should increase AWC. Therefore, the purpose of this study was to examine the effects of supplementation with CM, CM plus carbohydrate (CHO), or CHO alone on AWC. Using a double-blind random design, 26 young men (mean age \pm SD, 19.9 \pm 1.6 years) were assigned to 1 of 3 treatment conditions: (a) 35 g of flavored CHO powder as a placebo (PL, n = 8); (b) 5.25 g of CM and 1 g of CHO in a flavored powder blend (CM, n = 9); and (c) 5.25 g of CM and 33 g of CHO in flavored powder blend (CM-CHO, n = 9). The subjects completed 3 phases of testing on an electronically braked cycle ergometer: (a) familiarization (3 learning trials to establish power outputs for subsequent testing); (b) pretesting (4 bouts performed at power outputs selected to elicit fatigue in 1–10 minutes); and (c) posttesting (4 bouts performed at the same power outputs as pretesting but completed after ingesting the supplements 4 times per day for 6 consecutive days). The results indicated that CM and CM-CHO supplementation significantly ($p \leq 0.05$) increased AWC by 9.4 and 30.7%, respectively. These data suggest that 33 g of CHO may augment the effects of CM supplementation on AWC.

Key Words: ergogenic aids, anaerobic performance, cycle ergometry, nutritional supplement

Reference Data: Stout, J.R., J.M. Eckerson, T.J. Housh, and K.T. Ebersole. The effects of creatine supplementation on anaerobic working capacity. *J. Strength Cond. Res.* 13(2):135–138. 1999.

Introduction

Maximal anaerobic work is believed to be limited by the breakdown of the phosphagens adenosine triphosphate (ATP) and phosphocreatine (PC) (7). Hultman et al. (16) and Karlsson et al. (18) have dem-

onstrated that exercise intensities that elicit fatigue in 1 to 2 minutes may result in PC depletion. Furthermore, high-intensity exercise, such as running or cycling sprints lasting 4 to 30 seconds, have resulted in a 35 to 96% depletion of muscle PC levels, depending on the duration of the activity (24). One of the biochemical adaptations to sprint and weight training is a significant increase in muscle PC content, which has corresponded to an increase in exercise performance (7). Therefore, the ability to increase muscle PC content is an important training adaptation to high-intensity exercise.

Recently, investigators have attempted to manipulate muscle PC content in humans by oral supplementation with creatine monohydrate (CM) (9–11, 14). A limited number of studies have demonstrated that CM loading ($4 \times 5 \text{ g} \cdot \text{d}^{-1}$) for 5 to 6 days can significantly increase skeletal muscle creatine (Cr) content by an average of 20%, with PC accounting for 20% of the increase (9, 11, 14). Several studies have demonstrated ergogenic benefits of CM loading on isokinetic strength (12), running (3), cycle ergometry (1, 2, 5, 13), jumping (3, 25), and bench press (25) performance. Furthermore, Casey et al. (5) recently reported a significant correlation ($r = 0.72$, $p \leq 0.05$) between anaerobic performance during isokinetic cycling and skeletal muscle Cr retention from CM loading. The ergogenic benefits of CM loading, however, may vary significantly between subjects (5, 14). Harris et al. (14) recently reported large intersubject variation in muscle Cr retention from CM supplementation and suggested that this may be due to the initial levels of muscle Cr content. This may explain, in part, why some studies have reported no ergogenic benefits on anaerobic performance following CM loading (6, 23).

Recently, Green et al. (9) demonstrated that CM loading with carbohydrate (CHO) in human subjects resulted in a consistent increase in skeletal muscle Cr content that was significantly greater when compared with supplementation with CM alone. Green et al. (9)

suggested that the "augmentation of muscle Cr uptake after CM and CHO ingestion occurred as a result of the stimulatory effect of insulin on muscle Cr transport." Furthermore, Green et al. (9, 10) suggested that increasing Cr uptake with CHO may maximize the ergogenic benefits of CM supplementation. To date, however, no studies to our knowledge have compared CM with CM plus CHO supplementation on exercise performance.

A number of studies have found that anaerobic working capacity (AWC) from the critical power test (CP) provides a theoretically and experimentally valid estimate of work capacity associated with muscle energy reserves (ATP, PC) (4, 20, 21). Therefore, the purpose of this study was to determine the effects of CM vs. CM plus CHO supplementation on AWC.

Methods

Subjects

Twenty-six healthy men (mean age \pm SD, 19.9 \pm 1.6 years) volunteered as subjects for this investigation. Procedures were approved by the institutional review board before the initiation of the study, and subjects were informed of any possible risks before signing informed consent.

Supplementation Protocol

Following pretesting, the subjects were randomly assigned to 1 of 3 treatment conditions using a double-blind design: (a) 35 g of flavored dextrose (CHO) powder as a placebo (PL, $n = 8$); (b) 5.25 g of CM (Phosphagen, Experimental and Applied Sciences Inc., Golden, CO) plus 1 g of CHO in a flavored powder blend (CM, $n = 9$); and (c) 5.25 g of CM, 33 g of CHO, 633 mg of sodium and potassium phosphates, and 1 g of taurine in a flavored powder blend (CM-CHO, $n = 9$) (Phosphagen HP, Experimental and Applied Sciences). In a protocol similar to that of a study conducted by Hultman et al. (17), the subjects ingested the supplements 4 times a day for 6 consecutive days before returning to the laboratory for posttesting.

Critical Power Test

The subjects completed 3 phases of testing on a calibrated electronically braked cycle ergometer (Corival 400, Quinton Instruments): (a) the familiarization phase required the subjects to complete 3 learning trials to establish power outputs for subsequent testing; (b) pretesting consisted of 4 bouts performed at power outputs selected to elicit fatigue in 1 to 10 minutes; and (c) posttesting following supplementation required 4 work bouts at power outputs identical to those performed during pretesting.

The procedure for the CP test was the same as previously described by Moritani et al. (21). The power outputs for the exercise bouts ranged 200–375 W, depending on the fitness level of the subject. Rest periods

between each exercise bout continued until the subjects' heart rates returned to within 10 $\text{b}\cdot\text{min}^{-1}$ of preexercise levels; this typically took 30 minutes or longer (20–22). The subjects performed 2 of the exercise bouts on one day and 2 on another day, with at least 24 hours between testing sessions.

Before each exercise bout, the seat height of the cycle ergometer was adjusted for near full extension of the subjects' legs, while pedaling and foot straps were adjusted to prevent the feet from slipping off the pedals during testing. The subjects warmed up for 4 minutes by pedaling at a power output of 30 W. Following a 2-minute rest period, subjects began pedaling against zero resistance, and, upon reaching a pedaling rate of 70 rpm, the appropriate power output was applied within the first 2–3 seconds of the test. Each subject was encouraged to maintain the required pedaling rate throughout the entire exercise bout. The exercise bout was immediately terminated when the subject was unable to maintain 65 rpm as determined by the monitor on the ergometer. Time limit (TL) was recorded to the nearest 0.1 second. Work limit (WL) was calculated by multiplying power (P) and TL ($\text{WL} = P \times \text{TL}$). The AWC was the amount of work in kilojoules corresponding to the y-intercept of the WL–TL relationship as previously described (20–22).

Test-retest reliability data for AWC from the authors' laboratory for young men ($n = 11$) measured 7 days apart resulted in an intraclass correlation of 0.97 with a standard error of the mean of 0.59 kJ.

Data Analysis

Data were analyzed using a 3 by 2 (treatment by time) mixed-factorial analysis of variance (ANOVA) followed by Tukey post hoc analyses when a significant F ratio ($p \leq 0.05$) was observed.

Results

Table 1 summarizes the mean changes within the 3 groups for body weight (BW) and AWC. There were no significant ($p > 0.05$) changes in BW from pretesting to posttesting for any of the treatment groups. The 3 by 2 ANOVA for AWC, however, indicated a significant interaction ($p \leq 0.05$). Tukey post hoc comparisons indicated that subjects who had ingested CM and CM-CHO experienced significant ($p \leq 0.05$) increases in AWC of 9.4 and 30.7%, respectively. No significant changes for AWC occurred in the PL group.

Discussion

In theory, the AWC estimate represents the maximal work potential associated with muscle energy reserves (ATP, PC) (4, 20, 21). That is, in the absence of aerobic energy reconstitution, AWC is limited by the amount of energy available from stored ATP and PC. Monod and Scherrer (20) and Moritani et al. (21) indirectly

Table 1. Mean \pm SD of body weight and anaerobic working capacity following 6 days of creatine supplementation.

Parameter	PL ($n = 8$)	CM ($n = 9$)	CM-CHO ($n = 9$)
BW (kg) before supplementation	72.5 \pm 6.0	86.2 \pm 16.4	82.7 \pm 11.0
BW (kg) after supplementation	73.2 \pm 6.2	87.2 \pm 16.0	83.7 \pm 10.2
AWC (kJ) before supplementation	16.3 \pm 4.2	16.0 \pm 4.1	13.7 \pm 2.2
AWC (kJ) after supplementation	15.9 \pm 4.8	17.5 \pm 4.1*	17.9 \pm 3.5*

† CHO = creatine monohydrate plus carbohydrate; PL = 35 g CHO; CM = 5.25 g creatine monohydrate and 1 g CHO; CM-CHO = 5.25 g creatine monohydrate plus 33 g CHO; BW = body weight; AWC = anaerobic working capacity.

* AWC was significantly greater ($p \leq 0.05$) posttreatment than pretreatment.

supported this theory by demonstrating that the AWC estimate was unaffected when blood supply to working muscles by an arterial cuff was occluded or when the subjects were exercising at varying levels of hypoxia. The results of the present study demonstrated that CM loading for 6 days significantly ($p < 0.05$) increased AWC by 9.4 (CM) and 30.7% (CM-CHO). These results were in agreement with Hall et al. (13) and Earnest et al. (8), who reported comparable increases in AWC of 15% in adult men and women after CM loading for 5 days. Although muscle phosphagen levels were not directly measured in the present investigation, it is possible that the observed increase in AWC was due to an increase in muscle PC content. Previous studies that have directly measured muscle PC content following CM loading (20 g·d⁻¹) for 5 or 6 days demonstrated significant increases in PC stores by an average of 20% (5, 9–11, 14). Thus, AWC may serve as a sensitive, noninvasive procedure to assess changes in PC content from CM loading.

Previous studies that have examined the effect of CM loading on exercise performance have resulted in conflicting findings. Several studies have reported that CM loading resulted in improved performance for isokinetic strength (12), running (3), cycle ergometry (1, 2, 13), jumping (3, 25), and bench press (25). However, 2 recent studies (6, 23), which examined the effect of CM loading during high-intensity cycle ergometry, demonstrated no improvements in performance. Discrepancies in the literature regarding the effects of CM supplementation on performance may be attributed to the highly variable interindividual response in muscle Cr retention from CM loading (9, 14). Recently, Casey et al. (5) demonstrated a positive relationship ($r = 0.71$, $p < 0.05$) between anaerobic performance using cycle ergometry and the magnitude of muscle Cr retention from CM loading and concluded that the improvement in anaerobic performance was critically dependent on the magnitude of muscle Cr retention from CM loading.

Factors controlling muscle Cr retention following CM loading may include, but are not limited to, initial Cr levels, the effect of insulin on the transport of Cr into skeletal muscle, or both (9, 10, 14, 15, 19). Recent

studies have suggested that CM loading in subjects with a high initial muscle Cr content resulted in lower Cr retention and a diminished effect on anaerobic performance (5, 9, 14). Harris et al. (14), however, demonstrated that exercise, such as cycle ergometry, may augment skeletal muscle Cr retention by as much as 11.6% when compared with performing no exercise. Furthermore, it has been suggested that Cr retention was further enhanced by an increase in blood flow to the muscle, a change in the transport kinetics of Cr into the muscle, or both, which could have been mediated by an increased sensitivity to insulin induced by exercise (9, 10, 14).

Recently, Green et al. (9) reported that CM loading (20 g·d⁻¹) with an insulin-releasing CHO (370 g·d⁻¹) for 5 days resulted in a 60 and 51% greater increase in muscle Cr retention and PC content, respectively, vs. supplementation with CM alone. Green et al. (9) concluded that muscle Cr retention and PC content were further augmented when CM was taken with CHO and as a result may enhance the effects of CM loading on anaerobic performance. In agreement with Green et al. (9), the results of the present study demonstrated that CM-CHO supplementation resulted in a change in AWC that was 20% greater than when subjects supplemented with CM alone (Table 1). Because muscle PC levels were not directly measured in the present study, we were unable to determine if the improvement in AWC in the CM-CHO group was due to lower initial muscle Cr content or augmentation of muscle Cr retention and PC content. Future studies are warranted to confirm the present findings by comparing the effects of CM and CM-CHO supplementation on anaerobic performance and changes in muscle Cr content.

Practical Applications

The body weight change observed in this study for both Cr groups was 1.0 kg (Table 1), which was similar to values reported previously (0.9–1.8 kg) (24, 25); however, this change was not significant ($p > 0.05$). Furthermore, these results support previous studies (1–3, 5, 8, 12–14, 25) regarding the potential ergogenic

value of CM loading on anaerobic performance. In addition, supplementation with CM and CHO may augment the ergogenic effects by increasing Cr retention and PC content when compared with supplementation with CM alone (9, 10).

References

- BALSOM, P.D., B. EKBLUM, K. SODERLUND, B. SJODIN, AND E. HULTMAN. Creatine supplementation and dynamic high-intensity intermittent exercise. *Scand. J. Med. Sci. Sports*. 3:143–149. 1993.
- BIRCH, R., D. NOBLE, AND P.L. GREENHAFF. The influence of dietary creatine supplementation on performance during repeated bouts of maximal isokinetic cycling in man. *Eur. J. Appl. Physiol.* 69:268–270. 1994.
- BOSCO, C., J. TIHANYI, J. PUCSPK, I. KOVACS, A. GABOSSY, R. COLLI, G. PULVIRENTI, C. TRANQUILLI, C. FOTI, M. VIRU, AND A. VIRU. Effect of oral creatine supplementation on jumping and running performance. *Int. J. Sports Med.* 18:369–372. 1997.
- BULBULIAN, R., J.W. JEONG, AND M. MURPHY. Comparison of anaerobic components of the Wingate and Critical Power tests in males and females. *Med. Sci. Sports Exerc.* 28:1336–1341. 1996.
- CASEY, A., D. CONSTANTIN-TEODOSIU, S. HOWELL, E. HULTMAN, AND P.L. GREENHAFF. Creatine ingestion favorably affects performance and muscle metabolism during maximal exercise in humans. *Am. J. Physiol.* 271:E31–E37. 1996.
- COOK, W.H., P.W. GRANDJEAN, AND W.S. BARNES. Effect of oral creatine supplementation on power output and fatigue during bicycle ergometry. *J. Appl. Physiol.* 78:670–673. 1995.
- DEVRIES, H.A., AND T.J. HOUSH. *Physiology of Exercise: For Physical Education, Athletics and Exercise Science* (5th ed.). Madison: Brown and Benchmark, 1994. pp. 37–39.
- EARNEST, C.P., D.P. STEPHENS, AND J.C. SMITH. Creatine ingestion effects time to exhaustion during estimation of the work rate-time relationship. *Med. Sci. Sports Exerc.* 29(Suppl.):S285. 1997.
- GREEN, A.L., E. HULTMAN, I.A. MACDONALD, D.A. SEWELL, AND P.L. GREENHAFF. Carbohydrate ingestion augments skeletal muscle creatine accumulation during creatine supplementation in humans. *Am. J. Physiol.* 271:E821–E826. 1996.
- GREEN, A.L., E.J. SIMPSON, J.J. LITTLEWOOD, I.A. MACDONALD, AND P.L. GREENHAFF. Carbohydrate ingestion augments creatine retention during creatine feeding in humans. *Acta Physiol. Scand.* 158:195–202. 1996.
- GREENHAFF, P.L., K. BODIN, K. SODERLUND, AND E. HULTMAN. The effect of oral creatine supplementation on skeletal muscle phosphocreatine resynthesis. *Am. J. Physiol.* 266:E725–E730. 1994.
- GREENHAFF, P.L., A. CASEY, A.H. SHORT, R. HARRIS, K. SODERLUND, AND E. HULTMAN. Influence of oral creatine supplementation on muscle torque during repeated bouts of maximal voluntary exercise in man. *Clin. Sci.* 84:565–571. 1993.
- HALL, E.L., J.C. SMITH, D.P. STEPHENS, P.G. SNELL, AND C.P. EARNEST. Effect of oral ingestion of creatine monohydrate on parameters of the work-time relationship. *Med. Sci. Sports Exerc.* 25(Suppl.):S15. 1995.
- HARRIS, R.C., K. SODERLUND, AND E. HULTMAN. Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation. *Clin. Sci.* 83:367–374. 1992.
- HAUGHLAND, R.B., AND D.T. CHANG. Insulin effects on creatine transport in skeletal muscle. *Proc. Soc. Exp. Biol. Med.* 148:1–4. 1975.
- HULTMAN, E., J. BERGSTROM, AND N. MCLENNAN-ANDERSON. Breakdown and resynthesis of phosphorylcreatine and adenosine triphosphate in connection with muscular work in man. *Scand. J. Clin. Lab. Invest.* 19:56–66. 1967.
- HULTMAN, E., K. SODERLUND, J.A. TIMMONS, G. CEDERBLAD, AND P.L. GREENHAFF. Muscle creatine loading in men. *J. Appl. Physiol.* 81:232–237. 1996.
- KARLSSON, J., B. DIAMANT, AND B. SALTIN. Muscle metabolites during submaximal and maximal exercise in man. *Scand. J. Clin. Lab. Invest.* 26:385–394. 1971.
- KOSZALKA, T.R., AND C.L. ANDREW. Effect of insulin on the uptake of creatine-114C by skeletal muscle in normal and X-irradiated rats. *Pro. Soc. Exp. Biol. Med.* 139:1265–1271. 1972.
- MONOD, H., AND J. SCHERRER. The work capacity of a synergic muscular group. *Ergonomics* 8:329–338. 1965.
- MORITANI, T., A. NAGATA, H. DEVRIES, AND M. MURO. Critical power as a measure of physical work capacity and anaerobic threshold. *Ergonomics* 24:339–350. 1981.
- NEBELSICK-GULLETT, L.J., T.J. HOUSH, G.O. JOHNSON, AND S.M. BAUGE. A comparison between methods of measuring anaerobic work capacity. *Ergonomics* 31:1413–1419. 1988.
- ODLAND, L.M., J.D. MACDOUGALL, M.A. TARNOPOLSKY, A. ELORRIAGA, AND A. BORGMANN. Effect of oral creatine supplementation on muscle [PCr] and short-term maximum power output. *Med. Sci. Sports Exerc.* 29:216–219. 1997.
- VOLEK, J.S., AND W.J. KRAEMER. Creatine supplementation: Its effect on human muscular performance and body composition. *J. Strength Cond. Res.* 10:200–210. 1996.
- VOLEK, J.S., W.J. KRAEMER, J.A. BUSH, M. BOETES, T. INCLEDON, K.L. CLARK, AND J.M. LYNCH. Creatine supplementation enhances muscular performance during high-intensity resistance exercise. *J. Am. Diet. Assoc.* 97:765–770. 1997.

Acknowledgments

We would like to thank Experimental and Applied Sciences Inc. (Golden, CO) for funding this study.