TITLE: Effects of Creatine Monohydrate Supplementation on Simulated Soccer Performance

Submission Type: Original Investigation

Jeremy Williams[1], Grant Abt[2], Andrew E Kilding[1]
[1]Sports Performance Research Institute New Zealand, AUT University, Auckland, New Zealand
[2]Department of Sport, Health and Exercise Science, The University of Hull, Kingston upon Hull, United Kingdom

Corresponding author:
Dr Andrew Kilding
Sports Performance Research Institute New Zealand
AUT University
Auckland
New Zealand
Tel: +64 9 921 9999
Fax: +64 9 921 9960
Email: andrew.kilding@aut.ac.nz

Running head: Creatine and Soccer Performance

Abstract word count: 204

Text only word count: 2835

ABSTRACT

Purpose: To determine the effects of acute short-term creatine (Cr) supplementation on physical performance during a 90 minute soccer-specific performance test. **Methods:** A double-blind, placebo-controlled experimental design was adopted during which 16 male amateur soccer players were required to consume 20 g of Cr per day, for seven days or a placebo. A ball-sport endurance and speed test (BEAST) comprising measures of aerobic (circuit time), speed (12 and 20m sprint) and explosive power (vertical jump) abilities performed over 90 min was performed pre- and post-supplementation. **Results:** Performance measures during the BEAST deteriorated during the second half relative to the first for both Cr (1.2 to 2.3%) and placebo (1.0 to 2.2%) groups, indicating a fatigue effect associated with the BEAST. However, no significant differences existed between groups suggesting that Cr had no performance enhancing effect or ability to offset fatigue. When effects sizes were considered, some measures (12m sprint: -0.53 ± 0.69; 20m sprint: -0.39 ± 0.59 showed a negative tendency, indicating chances of harm were greater than chances of benefit. **Conclusions:** Acute short-term Cr supplementation has no beneficial effect on physical measures obtained during a 90 minute soccer simulation test, thus questioning its potential as an effective ergogenic aid for soccer players.

Keywords: intermittent, nutrition, ergogenic, team sport, football

INTRODUCTION

Many athletes use nutritional ergogenic aids in an attempt to improve both the quality and quantity of training, and to enhance their performance during competition [1]. Indeed, under specific conditions, many sporting ergogenic aids have been shown to have positive effects on athletic performance, body composition and strength [2] and it is possible that ingestion of additional nutrients may be necessary during high-intensity exercise to allow for maximal expression of endurance and strength gains [3].

Athletes participating in team sports may benefit from the consumption of nutritional ergogenic aids. Many team sports are characterised by high energetic demands (e.g. repeated high-intensity efforts) over long durations (~70-90 min), sometimes with short recovery periods [4,5]. One such ergogenic aid that has gained popularity is creatine monohydrate (Cr). Creatine is a naturally occurring compound derived from amino acids and is found primarily in skeletal muscle. Creatine exists in muscles as phosphocreatine (PCr), providing the high-energy phosphate for adenosine diphosphate (ADP) to restore adenosine triphosphate (ATP) concentration rapidly via the Cr kinase (CK) reaction [6]. Creatine can be ingested from natural exogenous sources, such as fish or red meat, ingested through supplementation, and produced endogenously by the body [7]. The average concentration of Cr in human muscle ([Cr]) is approximately 125 $mmol \cdot kg^{-1}$ dry mass, but following 7 days of Cr supplementation it has been reported to increase total muscle [Cr] by 20 to 50% [8,9].

Several studies to date have revealed beneficial effects of both chronic (>4 weeks) and acute (2 to 7 days) Cr supplementation on strength [10], power [8] and speed [11] in trained athletes. While most scientific support for the use of Cr to improve performance is associated with sports or single bout events requiring high anaerobic power[7], there is need for intermittent team sports athletes to repeatedly produce high-intensity explosive bouts typically over prolonged game durations (60-90 minutes). It is also possible that the ability to metabolically recover during high-intensity intermittent activity may be enhanced using oral Cr, given its role as a metabolic buffer [12], ability to reduce ATP loss during maximal exercise [13] and improve PCr resynthesis [14].

While it seems reasonable to suggest that team sport players could benefit from such Cr supplementation, with studies having reported positive effects of Cr on discrete physical performance tasks (e.g sprinting, jumping) relevant to team sport athletes [15-18]. However, few studies have reported the effects of acute Cr supplementation on actual or simulated soccer performance [19] over a full 90 minute (2 x 45 min) period. It is extremely difficult to quantify the effects of any type of intervention on actual soccer match play due to the high match-to-match variations in physical performance caused by factors such as changing opposition, the weather, the score, and position in league/competition. Likewise, the effects of a nutritional ergogenic aid on soccer performance cannot be validly assessed by simply quantifying physical performance effects measured in isolation from the true physical demands of prolonged intermittent activity. In an attempt to address this, Cox et al. [19] investigated the effects of acute Cr ingestion in female soccer players during a 5 x 12 min soccer simulation protocol with a total duration of 60 min and reported significantly faster sprint times in 9 of the 55 sprints. However, the mean sprint time for the Cr group was not significantly faster post-supplementation. Moreover, a consistent finding in studies of Cr supplementation is a significant increase in body mass of around 1.5 kg [20]. Conceivably, this increase in body mass in a weight-supported sport like soccer could decrease performance by increasing the energy cost of running. Given that muscle glycogen stores have been reported to be almost empty after a soccer match[21], then increasing the energy cost of running via an increased body mass would only exacerbate this problem.

Clearly there is a need for more research assessing the effects of acute short-term Cr supplementation using appropriate protocols that simulate the actual intensity demands and duration of a full game. Therefore, the aim of this study was to determine the acute effects of Cr supplementation on physical performance during a 90 minute soccer-specific simulation.

Methods

Experimental Design

A double-blind, placebo-controlled independent-groups design was adopted. Using a matched-pairs design, based on pre-intervention Yo-Yo Intermittent Recovery Test (YYIRT) scores, subjects were assigned to either an experimental group (Cr), or a placebo group. Before and after supplementation players were required to attend testing sessions involving familiarisation and two full trials of the Ball-sport Endurance And Sprint Test (BEAST) and YYIRT.

Subjects

With institutional ethics approval, 16 healthy male soccer players from an amateur soccer league volunteered to participate in the study. The descriptive characteristics of participants are presented in Table 1. Participants were pre-screened via medical questionnaire for any previous or current injuries and medical conditions that would contraindicate participation. In addition, participants were required to attest to having not consumed any sporting ergogenic aid(s) over the three month period prior to the study and agreed to provide dietary records two days prior to test sessions for later replication. Each subject provided written informed consent before any testing commenced.

Insert Table 1 about here

Test Protocols

All tests were conducted indoors in a well-ventilated, temperature controlled (~19^{o}C, 50-60%rH) sports facility.

Yo-Yo Intermittent Recovery Test

The YYIRT has been shown to be a reliable and valid test for assessing soccer-specific fitness [22]. The YYIRT consists of incremental shuttle running until exhaustion, with pace determined by an audible signal. Every second 20 m shuttle, players have ten seconds of active recovery consisting of 2 x 2.5 m walking. The test is terminated when the player fails to reach the line over two consecutive times (objective evaluation by two research assistants) or the player withdraws because of volitional exhaustion (subjective evaluation). The test score is the total distance (meters) covered during the test.

Soccer Simulation protocol

The BEAST protocol was designed from previous soccer match analysis studies [23-26] and has been reported to be valid and reliable [27]. The BEAST protocol consists of two laps that make up one circuit (Figure 1). Each circuit (380.4 m) is repeated continuously for 45 minutes (first half), followed by a half-time recovery period of ten minutes; then repeated for a further 45 minutes (second half). Sprinting, backwards jogging, walking, jogging / decelerating, and forwards running make up 8.4%, 8.4%, 9.7%, 24.5% and 39% of the total distance covered per circuit. During the BEAST, HR was measured continuously using a Polar Team HR system (Polar Electro, Oy, Kempele, Finland). Body-mass was measured and recorded to the nearest 0.1 kg pre-trial, at half-time and upon completion of the BEAST. Dual electronic timing lights (Speed-Light, Swift Performance, Melbourne, Australia) were used to record 12 m and 20 m sprint times during the entire BEAST protocol, as well as circuit time. A jump Mat (Swift Performance Melbourne, Australia) was used to measure vertical jump (VJ) height during each circuit of the BEAST. During the BEAST, participants were not permitted to drink, but water was provided during the half-time period. Ingested fluid volume was recorded and repeated for subsequent trials.

Insert Figure 1 about here

Supplementation

Subjects were supplemented with either Cr or a placebo (Cornflour, Edmonds, Auckland, NZ) for seven days following the initial pre-testing. All subjects received plastic vials each filled with 20 g of commercially available, 100% pharmaceutical grade, Cr monohydrate powder (Horleys, Auckland, New Zealand), which was mixed in with 8 g of flavored glucose powder to disguise the taste. The placebo group received plastic vials each filled with 20 g of cornflour, also mixed with 8 g of flavoured glucose powder making it indistinguishable from Cr in terms of flavour, texture and appearance. Subjects were verbally reminded each day to consume their prescribed supplement four times per day, with ~4 hours between dosages.

Creatine in Urine

Previous work has found that once Cr stores are filled after Cr supplementation, un-wanted Cr is excreted into the urine [28]. Participants were required to provide a 50 ml mid-catch, early morning, urine sample on days 1 (pre-supplementation) and 8 (post-supplementation) of the study. All samples were frozen at -40^{o}C until batch analysis.

Urinary Cr concentrations were determined before and after the dosing period in duplicate using an enzymatic colorimetric PAP test (Roche Diagnostics GmbH, Mannheim, Germany).

Statistical Analysis

Data were analysed using SPSS (Version 14.0) and specially created analysis spreadsheets for determination of confidence limits and qualitative interpretations of benefit and harm [29]. The effects of Cr supplementation were analysed by repeated measures ANOVA, with differences considered statistically significant when $P<0.05$. Most models included Group (Cr and placebo) as a between-subjects factor, Trial (pre and post) as a within-subjects factor and Interval (generally either two x 45 minutes or six x 15 minutes) as a second within-subjects factor. Bonferroni procedures were employed for post-hoc comparisons to reduce the probability of Type I errors. Cohen's *d* statistic was employed as the measure of effect size (ES) and defined as small (0.20), medium (0.50) and large (0.80). Hopkins' [29] spreadsheet was used to determine the ES and 90% confidence limits and the chances that the true effect was substantial.

Results

There were no significant differences between groups for any measure prior to Cr supplementation (Table 1). All subjects tolerated the Cr supplementation protocol with no reports of gastrointestinal distress, muscular cramping or other symptoms. Reported compliance of Cr ingestion was 100%. There was no evidence of weight gain after Cr supplementation (Cr: Pre, 79.8 ± 8.6 vs. Post, 79.7 ±10.4 kg; PLAC: Pre 80.8 ±10.5 vs. Post, 81.0 ±8.5 kg). The urinary Cr, determined pre- and post-Cr supplementation for both groups, is presented in Figure 2.

Insert Figure 2 about here

Pre- and post-supplement YYIRT and BEAST performance measures, per half and averaged over the full 90 minute protocol, are shown in Table 2. There were no significant main effects for Group or Trial, nor significant interaction effects (Group*Trial, Group*Interval, Trial*Interval, Group*Trial*Interval) for mean circuit time, 12 or 20 m sprint time or VJ height. Effect sizes of Cr (relative to placebo) over the full 90 minute BEAST protocol, and the chances that the true effect was substantial, are shown in Table 3.

Insert Table 2 about here
Insert Table 3 about here

Within trial comparisons, at 15 min intervals, are presented in Figures 3a-d for both PLAC and Cr.

Insert Figure 3a-d about here

DISCUSSION

Despite widespread use of Cr by athletes and numerous research studies and reviews investigating and evaluating its effect on performance [30], this study, to our knowledge, is the first to report the effects of Cr on physical performance during trials that closely replicate the true demands and duration of soccer match play.

Soccer is largely an aerobic sport [31] and well-developed aerobic fitness and the ability to repeatedly perform and recover from high-intensity exercise bouts [5] are essential to compete at the highest level. The lack of effect of Cr on mean circuit time during the BEAST in the present study is consistent with other studies which have investigated the effects of both short and long-term Cr ingestion on isolated measures of aerobic performance [32-35]. The lack of change in aerobic performance after acute short-term Cr supplementation seems logical from a physiological perspective, since the aerobic energy system is not dependent on PCr as an immediate energy source. However, we acknowledge that improved mean circuit time could be achieved by other Cr induced improvements in physical ability such as increased agility, jumping, sprinting ability [36] and recovery from such activities, caused by enhanced PCr and ATP resynthesis rates [14] and decreased muscle relaxation time [37]. Accordingly, we anticipated an increase in YYIRT performance after Cr supplementation, given that this test involves high intensity intermittent activity with limited recovery. Physiologically, it could be assumed that subjects in the Cr group would have an accelerated PCr recovery in between shuttles, due to the more freely available Cr for PCr resynthesis. Consistent with our findings for mean circuit time, enhanced YYIRT performance was not observed.

The progressive fatigue that occurs in soccer [38] has been attributed to several factors including the depletion of muscle glycogen, reductions in circulating blood glucose, hyperthermia, and dehydration [39]. It is plausible that the degree of fatigue observed during the BEAST (1.5 to 2.5% drop from 1st half to second half, Table 2) could be due to these mechanisms, and potentially from a depletion of PCr and decreased pH which have both been associated with the state of fatigue in skeletal muscle and the decline in muscle power during high-intensity exercise [40]. However, following Cr supplementation, there were no significant Group*Trial or Group*Trial*Interval interactions for any of the four BEAST performance measures (mean circuit time, 12 m sprint, 20 m sprint and VJ), body-mass or HR values, suggesting that Cr had no physical performance enhancing effect during the 90 minute BEAST protocol.

Although most previous soccer-related Cr studies have not used soccer-specific (jumps, turns, walking, running, sprinting etc) protocols of sufficient duration (90 mins), the results of the present study are in agreement with previous Cr studies that have utilised isolated physical tasks involving soccer players [18] or other team sport athletes [8,36,41,42]. However, the present results oppose the reported enhancement in sprint performance seen in other soccer-related [15-17,32] and team sport studies [8,32]. The study by Cox et al [19], involving 14 elite female soccer players, is most relevant as it investigated the effects of six days of Cr supplementation (20 $g.day^{-1}$) during 5 x 12 minute exercise bouts involving 20 m sprints, agility, and a ball kicking drill, separated by recovery walks, jogs and runs. In contrast to our findings, the Cr group achieved consistently faster post-supplementation times between sprints 10 and 47, reaching statistical significance for nine (out of 55; 16%) 20 m sprints, although there was no significant improvement in the mean sprint time. Agility was also improved (2.2%). The conflicting outcomes of the present study and that of Cox et al [19] could be due to differences in gender and playing level of the subjects, the shorter duration of the adopted protocol and, though not reported by Cox et al [19], differences in subjects' Cr stores compared to the present study. This would explain the reported improvements in sprint times as well as increased body-mass after Cr supplementation in the Cox et al [19] study but not ours.

As previously discussed there is usually an increase in body mass of around 1.5 kg following acute Cr supplementation. Although in the present study there was no significant change in body mass in the Cr group following supplementation, we did observe a large increase in urinary Cr post-supplementation (Figure 2). The mean post-supplementation urinary Cr concentration was greater than 10 times the resting concentration of the placebo group, suggesting that those in the Cr group had sufficiently increased total muscle [Cr] to a level where the majority of ingested Cr was being excreted in the urine. Although an increase in body mass following Cr supplementation is usual, it does not always occur. Studies by Zuniga et al[43] and Reardon et al.[44] both failed to observe an increase in body mass following Cr supplementation. The reasons for why body mass did not increase following Cr supplementation in the current study are unknown, but based on the urinary Cr data those in the Cr group should have substantially increased their [Cr] after supplementation. However, we also acknowledge that given the absence of muscle [Cr] measures in the present study, it is possible that both groups in our study already had elevated muscle Cr stores at baseline and that Cr supplementation had little impact on increasing muscle [Cr]. This could also explain the lack of change in body mass and performance measures following supplementation.

In the present study, explosive leg power, as measured by the VJ test during the BEAST protocol, was not enhanced by acute Cr supplementation. These findings are in agreement with Miszko et al [42] and Mujika et al [16], who found no change in VJ or counter movement jumps (CMJ) respectively, after acute short-term Cr ingestion. In contrast, Ostojic [17] reported a 10.8% increase in VJ performance after 7 days of Cr supplementation in young soccer players. Similarly, Izquierdo et al [32] also reported CMJ values to increase (5.1%) after acute short-term Cr supplementation.

When assessed for the whole 90 minute BEAST protocol, all effects of Cr were negative and correspondingly, the chances of a detrimental effect were greater than the chances of a beneficial effect. This is important as it illustrates the potentially greater chance for Cr to be harmful than to be beneficial to performance which opposes previous findings of a neutral effect of Cr on aerobic performance [45]. For 12 and 20 m sprint time, the chances of Cr having a beneficial effect were considered very unlikely (1 to 5%). The disparity between likelihoods of benefit versus harm for mean circuit time and vertical jump were insufficient for a clear assessment to be made, however, the likelihoods of a detrimental effect were 8.7 and 4.1 times greater for circuit time and vertical jump respectively.

Practical Applications

From an applied perspective, the lack of effect of Cr supplementation on physical performance tests that closely simulate the intensity and duration of soccer indicates that its use as an ergogenic aid in prolonged intermittent team sports is questionable.

Conclusion

In summary, the findings of the present study suggest that short-term Cr supplementation does not enhance repeated high-intensity or prolonged soccer-specific exercise performance. Furthermore, the tendency of magnitude-based practical inferences to reveal greater chances of harm than benefit would indicate that consumption of Cr is not a worthwhile strategy for soccer players.

REFERENCES

1. Sundgot-Borgen J, Berglund B, Torstveit M. Nutritional supplements in Norwegian elite athletes - impact of international ranking and advisors. *Scand J Med Sci Sports.* 2003;13:138-144.

2. Beduschi G. Current popular ergogenic aids used in sports: a critical review. *Nutr Diet.* 2003;60:104-118.

3. Nissen S, Sharp R. Effect of dietary supplements on lean body mass and strength gains with resistance exercise: a meta-analysis. *J App Physiol.* 2003;94:651-659.

4. Austin D, Gabbett T, Jenkins D. Repeated high-intensity exercise in professional rugby union. *J Sports Sci.* Jul 2011;29(10):1105-1112.

5. Bangsbo J, Mohr M, Krustrup P. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci.* 2006;24(7):665-674.

6. Clarkson P. Nutrition for Improved Sports Performance. *Sports Med.* 1996;21(6):393-401.

7. Bemben M, Lamont H. Creatine supplementation and exercise performance. *Sports Med.* 2005;35(2):107-125.

8. Ahmun R, Tong, R., & Grimshaw, P. The effects of acute creatine supplementation on multiple sprint cycling and running performance in rugby players. *J Strength Cond Res.* 2005;19(1):92-97.

9. Hultman E, Soderlund K, Timmons J, Cederblad G, Greenhaff P. Muscle creatine loading in men. *J App Physiol.* 1996;81(1):232-237.

10. Bemben M, Bemben D, Loftiss D, Knehans A. Creatine supplementation during resistance training in college football athletes. *Med Sci Sports Exer.* 2001;33(10):1667-1673.

11. Aaserud R, Gramvik P, Olsen SR, Jensen J. Creatine supplementation delays onset of fatigue during repeated bouts of sprint running. *Scand J Med Sci Sports.* 1998;8:247-251.

12. Hultman E, Sahlin K. Acid-base balance during exercise. *Exerc Sport Sci Rev.* 1980;8:41-128.

13. Greenhaff PL, Casey, A., Short, A.H., Harris, R.C., Soderlund, K. The influence of oral creatine supplementation on muscle torque during repeated bouts of maximal voluntary exercise in man. *Clin Sci.* 1993;84
565-571.

14. Greenhaff P, Bodin K, Soderlund K, Hultman E. Effect of oral creatine supplementation on skeletal muscle phosphocreatine resynthesis. *Am J Physiol.* 1994;266:E725-E730.

15. Cox G, Mujika, I., Tumilty, D., & Burke, L. Acute creatine supplementation and performance during a field test simulating match play in elite female soccer players. *J Sport Nutr Exer Metab.* 2002;12:33-46.

16. Mujika I, Padilla S, Ibanez J, Izquierdo M, Gorostiaga E. Creatine supplementation and sprint performance in soccer players. *Med Sci Sports Exer.* 2000;32(2):518-525.

17. Ostojic S. Creatine supplementation in young soccer players. *Int J Sport Nutr Exerc Metab.* 2004;14:95-103.

18. Smart N, McKenzie S, Nix L, et al. Creatine supplementation does not improve repeat sprint performance in soccer players. *Med Sci Sports Exer.* 1998;30(5):S140.

19. Cox G, Mujika I, Tumilty D, Burke L. Acute creatine supplementation and performance during a field test simulating match play in elite female soccer players. *Int J Sport Nutr Exer Metab.* Mar 2002;12(1):33-46.

20. Tarnopolsky MA. Caffeine and creatine use in sport. *Ann Nutr Metab.* 2010;57:1–8.
21. Krustrup P, Mohr M, Steensberg A, Bencke J, Kjaer M, Bangsbo J. Muscle and blood metabolites during a soccer game: implications for sprint performance. *Med Sci Sports Exer.* Jun 2006;38(6):1165-1174.
22. Krustrup P, Mohr M, Amstrup T, et al. The Yo-Yo Intermittent Recovery Test: Physiological response, reliability, and validity. *Med Sci Sports Exer.* 2003;35(4):697-705.
23. Bangsbo J, Norregaard L, Thorso F. Activity profile of competition soccer. *Can J Sport Sci.* 1991;16(2):110-116.
24. Mayhew S, Wenger H. Time motion analysis of professional soccer. *J Hum Mov Stud.* 1985;11:49-52.
25. Reilly T, Thomas V. A motion analysis of work-rate in different positional roles in professional football match-play. *J Hum Mov Stud.* 1976;2:87-97.
26. Withers R, Maricic Z, Wasilewski S, Kelly L. Match analysis of Australian professional soccer players. *J Hum Mov Stud.* 1982;8:159-176.
27. Williams JD, Abt G, Kilding AE. Ball-Sport Endurance and Sprint Test (BEAST90): validity and reliability of a 90-minute soccer performance test. *J Strength Cond Res.* Dec 2010;24(12):3209-3218.
28. Greenhaff P. The nutritional biochemistry of creatine. *J Nutr Biochem.* 1997;8:610-618.
29. Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. . *Sportsci.* 2007;11:16-20.
30. Cooper R, Naclerio F, Allgrove J, Jimenez A. Creatine supplementation with specific view to exercise/sports performance: an update. *J Int Soc Sports Nutr.* 2012;9(1):33.
31. Hoff J, Helgerud J. Endurance and strength training for soccer players. *Sports Med.* 2004;34(3):165-180.
32. Izquierdo M, Ibanez J, Gonzalez-Badillo J, Gorostiaga E. Effects of creatine supplementation on muscle power, endurance and sprint performance. *Med Sci Sports Exerc.* 2002;34(2):332-343.
33. Reardon T, Ruell P, Fiatarone Singh M, Thompson C, Rooney K. Creatine supplementation does not enhance submaximal aerobic training adaptions in healthy young men and women. *Eur J Appl Physiol.* 2006;98:234-241.
34. Van Loon L, Oosterlaar M, Hartgens F, Hesselink M, Snow R, Wagenmakers A. Effects of creatine loading and prolonged creatine supplementation on body composition, fuel selection, sprint and endurance performance in humans. *Clin Sci.* 2003;104:153-162.
35. Vandebuerie F, Vanden Eynde B, Vandenberghe K, Hespel P. Effect of creatine loading on endurance capacity and sprint power in cyclists. *Int J Sports Med.* 1998(19):490-495.
36. Redondo DR, Dowling EA, Graham BL, Almada AL, Williams MH. The effect of oral creatine monohydrate supplementation on running velocity. *Int J Sport Nutr.* 1996;6:213-221.
37. Van Leemputte M, Vandenberghe K, Hespel P. Shortening of muscle relaxation time after creatine loading. *J Appl Physiol* 1999;86(3):840-844.
38. Mohr M, Krustrup P, Bangsbo J. Fatigue in soccer: A brief review. *J Sports Scis.* 2005;23(6):593-599.
39. Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci.* 2003;21:519-528.

40. Cooke S, Petersen S, Quinney H. The influence of maximal aerobic power on recovery of skeletal muscle following anaerobic exercise. *Eur J Appl Physiol.* 1997;75:512-519.

41. Cornish S, Chilibeck P, Burke D. The effect of creatine monohydrate supplementation on sprint skating in ice-hockey players. *J Sports Med Phys Fit.* 2006;46:90-98.

42. Miszko T, Baer J, Vanderburgh P. The effect of creatine loading on body mass and verticle jump of female athletes. *Med Sci Sports Exerc.* 1998;30(5):S141.

43. Zuniga JM, Housh TJ, Camic CL, et al. The effects of creatine monohydrate loading on anaerobic performance and one-repetition maximum strength. *J Strength Cond Res.* Jun 2012;26(6):1651-1656.

44. Reardon TF, Ruell PA, Fiatarone Singh MA, Thompson CH, Rooney KB. Creatine supplementation does not enhance submaximal aerobic training adaptations in healthy young men and women. *Eur J Appl Physiol.* Oct 2006;98(3):234-241.

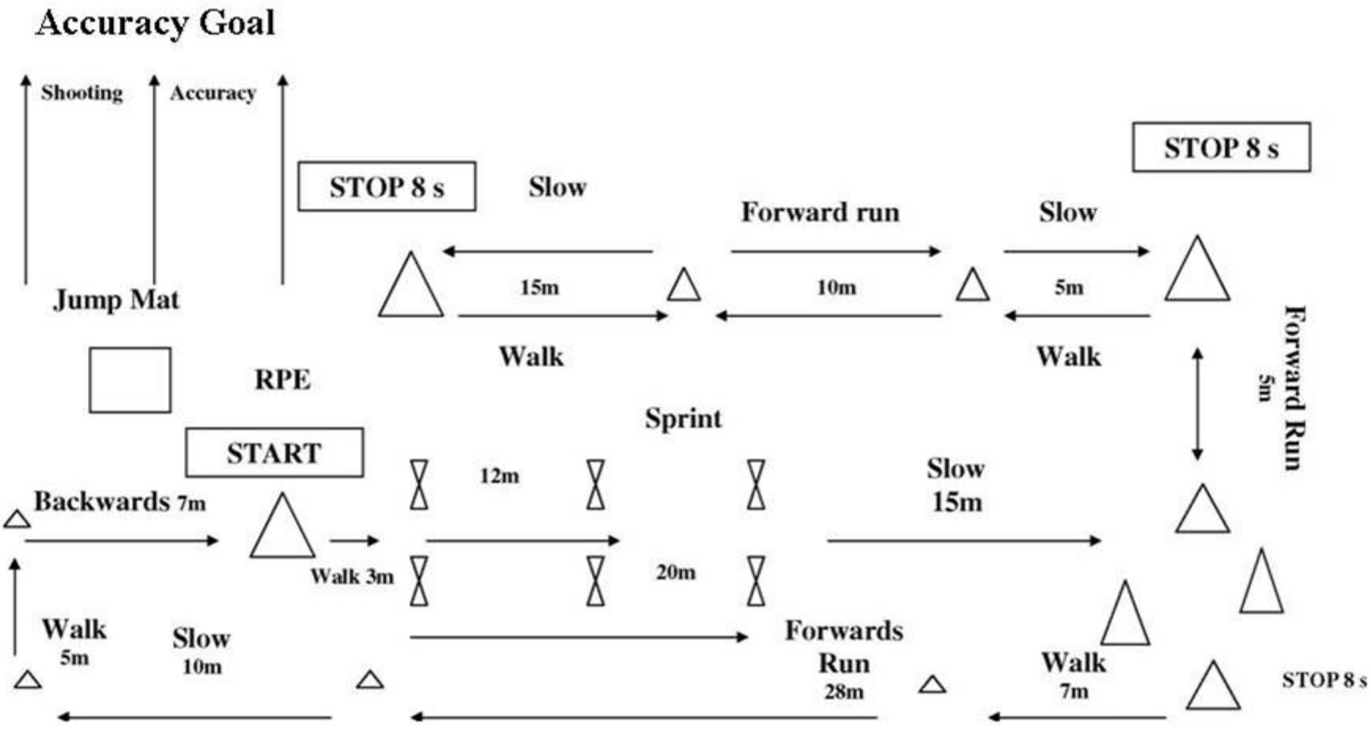
45. Smith AE, Fukuda DH, Ryan ED, Kendall KL, Cramer JT, Stout J. Ergolytic/ergogenic effects of creatine on aerobic power. *Int J Sports Med.* Dec 2011;32(12):975-981.

Figure Legends

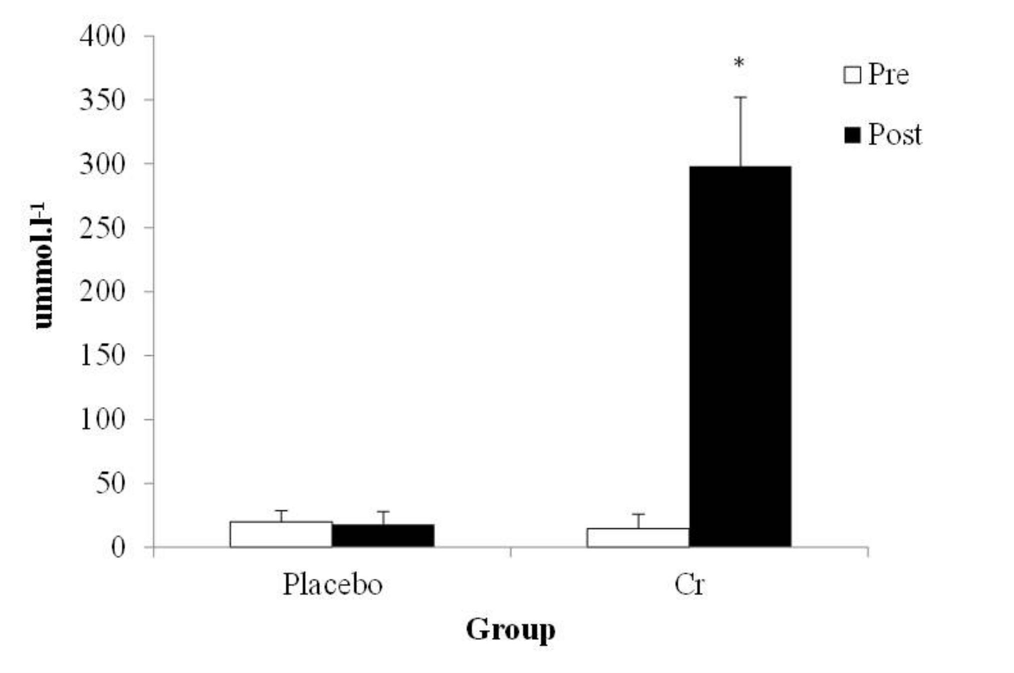
Figure 1. Schematic representation of the Ball-Sport Endurance and Speed Test (BEAST).

Figure 2. Urinary creatine pre- and post-supplementation

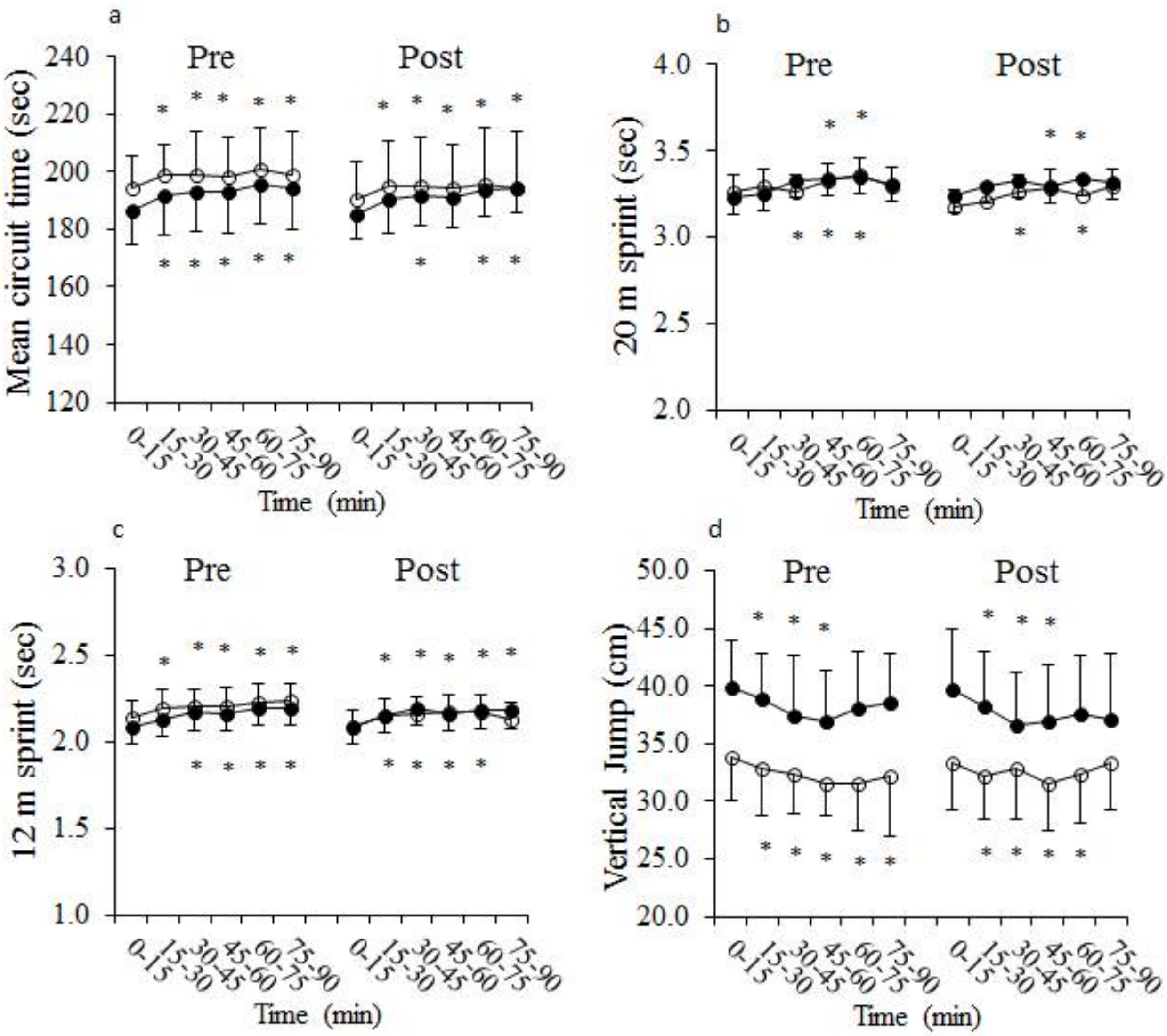
Figure 3a-d. Mean (±SD) 15-minute interval performance for a) mean circuit time; b) 20 m sprint time; c) 12 m sprint time and d) vertical jump height during the BEAST protocol, pre- and post-supplementation, for both the Cr (●) and PLAC (○) groups. * represents significant difference between the first 15 min interval and subsequent intervals.



Accuracy Goal
Shooting
Accuracy
STOP 8 s
Slow
Forward run
Slow
STOP 8 s
15m
10m
5m
Jump Mat
Walk
Walk
Forward Run
5m
RPE
Sprint
START
12m
Slow
15m
Backwards 7m
Walk 3m
20m
Walk
5m
Slow
10m
Forwards
Run
28m
Walk
7m
STOP 8 s



400
350
300
250
200
150
100
50
0
ummol.l-1
*
Pre
Post
Placebo
Cr
Group



a
Pre
Post
Mean circuit time (sec)
Time (min)
b
20 m sprint (sec)
c
12 m sprint (sec)
d
Vertical Jump (cm)
0-15
15-30
30-45
45-60
60-75
75-90

Table 1. Participant descriptive characteristics. Values are mean ± SD

Group	Age (years)	Height (cm)	Body-mass (kg)	Playing Experience (years)	YYIRT (m)
Creatine (n=8)	25.4 ± 4.5	179.3 ± 4.6	79.3 ± 10.5	18.7 ± 5.4	1068 ± 473
Placebo (n=8)	26.7 ± 4.6	178.9 ± 5.1	80.8 ± 8.6	19.4 ± 4.3	1065 ± 387

Table 2. Pre- and post-supplement physical performance variables during the BEAST. Values are mean ± SD.

	Creatine Group (n = 8)		Placebo Group (n = 8)	
	Pre	Post	Pre	Post
Mean circuit time (s)				
1st Half	190 ± 13	189 ± 10	196 ± 11	193 ± 15
2nd Half	193 ± 13*	192 ± 8*	199 ± 14*	195 ± 17*
Total	193 ± 12	191 ± 8	198 ± 13	194 ± 19
Mean 12 m sprint time (s)				
1st Half	2.13 ± 0.14	2.13 ± 0.13	2.18 ± 0.08	2.13 ± 0.09
2nd Half	2.18 ± 0.19*	2.18 ± 0.16*	2.22 ± 0.11*	2.16 ± 0.11*
Total	2.16 ± 0.14	2.16 ± 0.04	2.20 ± 0.09	2.15 ± 0.08
Mean 20 m sprint time (s)				
1st Half	3.24 ± 0.22	3.28 ± 0.21	3.28 ± 0.14	3.21 ± 0.15
2nd Half	3.32 ± 0.18*	3.32 ± 0.22*	3.33 ± 0.17*	3.25 ± 0.20*
Total	3.30 ± 0.20	3.30 ± 0.04	3.30 ± 0.15	3.23 ± 0.19
Mean vertical jump height (cm)				
1st Half	38.8 ± 8.7	38.3 ± 8.8	33.1 ± 4.7	31.5 ± 7.1
2nd Half	37.7 ± 7.9	37.2 ± 9.1	31.6 ± 4.8*	30.8 ± 7.8
Total	38.3 ± 1.0	37.7 ± 1.2	32.4 ± 4.7	31.1 ± 7.7
Heart rate ($b{\cdot}min^{-1}$)				
1st Half	166 ± 13	165 ± 14	168 ± 8	166 ± 12
2nd Half	160 ± 11*	159 ± 13*	167 ± 9	164 ± 10
Total	164 ± 11	162 ± 14	164 ± 8	166 ± 10
RPE (AU)				
1st Half	12.4 ± 1.5	12.2 ± 1.1	12.9 ± 1.7	12.6 ± 1.4
2nd Half	14.0 ± 2.3*	13.8 ± 2.4*	14.7 ± 1.7*	13.1 ± 1.9
Total	13.2 ± 2.1	13.1 ± 2.0	14.2 ± 1.4	12.9 ± 1.8

Where * = Significant difference between 1st and 2nd halves, $P<0.05$.

Table 3. Effect of creatine (relative to placebo) on physical performance measures during the 90 minute BEAST and YYIRT.

Performance Measure	Cohen ES[1]	Chances that the true effect was substantial[2]		
		Benefit %	Harm %	Practical Assessment[3]
Circuit Time	-0.22 ± 0.54	6	52	Unclear
12 m Sprint	-0.53 ± 0.69	2	84	Benefit very unlikely/harm possible
20 m Sprint	-0.39 ± 0.59	3	75	Benefit very unlikely/harm possible
VJ	-0.13 ± 0.48	9	37	Unclear
YYIRT	-0.12 ± 0.63	14	40	Unclear

[1] ES values are shown as positive where the effect of Cr is beneficial and negative where the effect is detrimental. Values are ES ± 90% confidence interval.
[2] Cohen ES ≥ 0.2 [29]
[3] If chance of benefit or harm were both >5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain.