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The effect of combined supplementation of carbohydrates and creatine on anaerobic performance

AUTHORS: Theodorou AS[1], Paradisis G[1], Smpokos E[2], Chatzinikolaou A[3], Fatouros I[3], King RFGJ[4], Cooke CB[5]

[1] School of Physical Education & Sport Sciences, National and Kapodistrian University of Athens, Athens, Greece
[2] Department of Social Medicine, Preventive Medicine & Nutrition Clinic, Faculty of Medicine, University of Crete, Heraklion, Greece
[3] School of Physical Education & Sport Sciences, Democritus University of Thrace, Komotini, Greece
[4] Carnegie School of Sport, Leeds Beckett University, Leeds, UK
[5] School of Social and Health Sciences, Leeds Trinity University, Leeds, UK

Corresponding author:
A. S. Theodorou
School of Physical Education
& Sport Sciences
University of Athens
Ethinis Antistaseos 41
17237, Athens, Greece
E-mail: aptheod@phed.uoa.gr
Tel: 0030 6947570439
Fax: 0030 210 7276175

ABSTRACT: The purpose of the study was to examine the effect of creatine (Cr) supplementation on anaerobic performance when ingesting creatine and carbohydrates (CHO) together. Twenty male physical education students comprised the two experimental (CR and CRCHO) and one control (CON) groups of the study. All groups performed three 30 s anaerobic Wingate tests (AWTs) interspersed with 6 minutes of recovery. The CR group (n = 7) ingested 5 g of Cr 5 times per day for 4 days. Subjects in the CRCHO group (n = 6) ingested the same quantity but additionally after each 5 g dose of Cr consumed 500 ml of a commercially available energy drink containing 100 g of simple sugars. Over all three AWTs average mean power improved significantly compared to baseline for the CR group (5.51%) but not for the CRCHO group (3.06%). Mean power for the second AWT was improved following the acute loading for the CR group only (4.54%) and for the third AWT for both CR (8.49%) and CRCHO (5.75%) groups. Over all three AWTs a significant change was recorded in average peak power following the acute loading for the CR group (8.26%) but not for the CRCHO group (4.11%). Peak power was significantly improved following the loading only for the CR group during the third AWT (19.79%). No changes in AWT performance were recorded for the CON group after intervention. The findings of the present study suggest that ingesting creatine together with carbohydrates will not further improve performance compared to the ingestion of creatine only.

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INTRODUCTION

The role of creatine (Cr) in energy metabolism as a substrate (in the form of phosphocreatine – PCr) for the maintenance of a high intracellular adenosine triphosphatase (ATP) / adenosine diphosphatase (ADP) ratio in muscle, during intense activity, through the creatine kinase reaction is well documented [1]. Most studies investigating the effect of Cr supplementation on exercise performance have used a loading scheme, by ingesting a dose of 20-25 g/day for 4-5 days [2-4]. This scheme, also known as "acute Cr loading", upregulates total muscle creatine and phosphocreatine to a point considered necessary to improve exercise performance [5, 6]. In fact, a positive relationship has been established between the magnitude of elevation of the muscle total Cr content following acute creatine loading and the extent of performance enhancement [6, 7].

Previous studies reported that muscle creatine uptake may be enhanced if Cr is administered with insulin [8]. Green et al. [9, 10] first reported that the combination of Cr supplementation with carbohydrate (CHO) ingestion may substantially increase muscle Cr uptake (60%) in man to a point beyond that associated with an acute creatine loading alone, probably due to the enhanced insulin levels in the circulation [11, 12]. In that study, a drink containing 93 g of simple sugars was consumed 30 minutes after the ingestion of 5 g of Cr, 4 times each day. Steenge et al. [12] reported that ingesting Cr in combination with ~100 g of CHO is effective at potentiating insulin release and creatine retention. Furthermore, Greenwood et al. [13] established that even substantially lower doses of CHO (i.e. ingestion of 18 g of dextrose) with creatine monohydrate (5 g) significantly augments whole body creatine retention over a three-day period compared to ingesting creatine monohydrate alone. Nonetheless, neither of the studies that demonstrated a higher muscle creatine concentration as a consequence of the addition of CHO to a dietary

creatine-loading regimen included performance measures and assessment of the ergogenic potential of combined creatine and CHO supplementation. Theodorou et al. [14], replicating the supplementation protocol of Green et al. [10], compared changes in performance over repeated bouts of maximal swimming in two groups of elite swimmers following an acute loading protocol of either creatine alone or creatine along with carbohydrates and reported that all swimmers improved performance after administration, but neither regimen appeared to offer a superior ergogenic advantage. Surprisingly, no studies have followed on this topic investigating further the potential ergogenic effects of Cr + CHO administration on performance under both field and laboratory conditions.

In the present study, we tested the hypothesis that the combined ingestion of creatine and carbohydrates would enhance the anaerobic performance of active individuals during repeated bouts of high-intensity exercise compared to the administration of creatine alone. A testing protocol consisting of three repeated maximum intensity bouts of a 30 s AWT, interspersed with 6 minutes of recovery, has been found to maximally stress the creatine phosphate pathway, as creatine phosphate concentration at the end of the 3rd AWT represents only 14% of the values measured at rest [15]. Several studies [16-19] have demonstrated that such a protocol provides a sensitive and reproducible method for assessing the ergogenic properties of dietary creatine loading. We therefore hypothesized that this same test would provide a sensitive performance model for comparing the efficacy of combined creatine and CHO loading with that of creatine loading alone.

MATERIALS AND METHODS

Participants

Twenty healthy and physically active male sports science students (age 24 ± 5 years; body mass 72.4 ± 8 kg; height 1.77 ± 0.07 m) participated in the present study. All subjects gave informed consent. The study received ethical approval from the University Healthcare Research Ethics Committee.

Experimental design

The study was conducted within a 2-week period. Initially (first week), exercise testing was performed (n = 20) prior to any supplementation (baseline). The participants underwent three continuous 30 s all-out cycle sprints interspersed with 6-minute active recovery intervals. This exercise protocol has also shown high reproducibility over repeated testing (0.9% difference in peak power values; paired t-test and limits of agreement – Bland and Altman) in a previous study [20]. The AWT was performed on a MONARK 814e cycle ergometer (Monark Exercise AB, Vansbro, Sweden). The ergometer was bolted to the floor in order to provide greater stability during maximal cycling. Before starting the test, a belt which was attached to the wall below the level of the saddle was placed around the participant's waist in order to prevent him from rising off the saddle. A standardised warm-up preceded the test; it involved 5 minutes of cycling at 60 rpm with a load of 0.5 kg. During the AWT, participants had to pedal against a fixed resistance that was calculated according to their body mass. The resistance used in the present study was 0.075 $kg.kg^{-1}$ body mass. This resistance was suggested originally by the Wingate group, assuming the use of a Monark ergometer, and is also used in the computer package (CONEPT II) developed by Lakomy [21]. All subjects received strong verbal encouragement throughout the testing protocol. Prior to the commencement of the above exercise testing all subjects followed a familiarization protocol which consisted of a series of 6 s cycle sprints during a three-day period. This habituation process has been shown to be effective for the establishment of the maximal volitional effort for sedentary, active and athletic subjects [22, 23].

The AWT indices of peak power (for each second of the 30 s test) and average mean power (over the whole 30 s test) were recorded. The following performance parameters were then calculated: absolute mean power (AMP) for each AWT, absolute mean power over all three AWTs (AMP_{all}), relative mean power (RMP) for each AWT, relative mean power over all three AWTs (RMP_{all}), absolute peak power (APP) and relative peak power (RPP) for each AWT, mean peak power over all three AWTs in absolute (APP_{all}) and relative (RPP_{all}) values.

Following baseline exercise testing, participants were randomly divided into three groups: a creatine group (CR, n = 7), a creatine plus carbohydrate group (CRCHO, n = 6) and a control group (CON, n = 7) and supplements or placebo were administered in a single-blind design. Two days after completing supplementation, participants repeated the same exercise testing procedure as in baseline under the same time and laboratory conditions.

Supplementation protocol

Pure creatine monohydrate (H5 Ltd, Leicestershire, UK) in the form of dry white powder was used in this study. The chemical composition of creatine supplements was assessed via repeated measures using a PYEUNICAM8 spectrophotometer [24].

The dosage used for the acute loading was 5 g of creatine in 1.5-2 hour intervals dissolved in 200 ml of water, 5 times each day over a 4-day period. Subjects in the CON group ingested placebo (Polyethylene Glycol 4000) instead of creatine (in the same supplementation scheme as in the CR group). Subjects in the CRCHO group were administered creatine (in the same supplementation scheme as in the CR group) and 500 ml of a commercially available energy drink (Lucozade Energy, ~ 18.5% w/v glucose and simple sugars, Smithkline Beecham, Coleford, UK) 30 minutes after consuming each creatine dose. This same energy drink, containing as stated on the label of the bottle approximately 100 g of simple sugars, was also used in the original studies of Green et al. [9, 10] assessing the effects of carbohydrate ingestion on creatine muscle uptake and retention. Participants in the CR group were also instructed to refrain from eating for at least 90 minutes after creatine ingestion in order to avoid an increased insulin response similar to that in the CRCHO group. Participants also completed seven-day food records during

the baseline week in order to assess total energy and macronutrient content using Comp-Eat Version 4 nutrient analysis software. Afterwards, they were instructed to follow a daily carbohydrate, protein and caloric intake, similar to the baseline week, for the following two weeks (Cr and Cr+CHO). Water and non-caloric/non-caffeine drinks were consumed *ad libitum*.

Blood sampling

A total of five venous blood samples were collected from each subject pre- and post-loading for lactate measurement: at rest (LR), immediately after each AWT (L1, L2, L3), and 10 minutes following the completion of the third AWT (LF). Lactate concentration represents an indication of the degree of acidity in the circulation post-exercise and can be used as a marker of fatigue associated with the AWTs. A 32 mm catheter placement unit was used for collection of the blood samples using 2 ml syringes (MICROLANE 3). Blood samples were aliquoted into tubes containing 1 ml of trichloroacetic acid (TCA). These tubes were weighed before and after the addition of TCA as well as after the addition of the blood sample. Blood lactate concentration was determined by an enzymatic method [25] with an LKB8600 reaction rate analyzer (LKB-Producter AB, Bromma, Sweden). The values obtained were corrected for blood and trichloroacetic acid density and expressed in mmol.l-1 of whole blood.

Statistical analysis

All experimental data are presented as means ± standard deviations. Data normality was verified with the 1-sample Kolmogorov-Smirnov test and sphericity through Mauchly's test; therefore, a nonparametric test was not necessary. Exercise performance data were analysed by a mixed 3 x 2 ANOVA (group: CR vs. CRCHO vs. CON x time: baseline and post supplementation) with repeated measures on one factor (time). ANOVA with repeated measures (condition factor) was also used in dietary analysis in order to detect differences among nutrient parameters. When a significant interaction or main effect was found, pairwise comparisons were performed through simple main effect analysis. Significance was set at an alpha of 0.05 for all analyses.

RESULTS

Body mass

A main effect of time on body mass was detected ($p = .002$, $F = 13.56$, $\eta^2 = 0.46$). A pairwise comparison revealed that body mass increased significantly both in the CR group (72.6 ± 9.5 kg at baseline vs. 73.3 ± 8.9 kg post-supplementation, $p = .047$) and in the CRCHO group (71.0 ± 5.7 kg at baseline vs. 72.1 ± 5.7 kg post-supplementation, $p = .007$). No significant interactions were detected between the two groups ($p = .739$). No significant statistical difference was found for the control group (72.3 ± 8.4 kg at baseline vs. 72.6 8.4 kg post-supplementation, $p = .353$).

Absolute mean power

A main effect of time ($p < .001$, $F = 39.02$, $\eta^2 = 0.71$) was found for AMP_{all}. Paired comparisons between the two time points (before and after supplementation) revealed significant increases in AMP_{all} ($p < .001$) in the CR and CRCHO groups ($p = .003$). No difference was found for the control group ($p = .434$). No significant interactions were detected between groups.

When each AWT was analysed individually, a main effect of time was found for absolute mean power ($p < .001$). Paired comparisons revealed a significant absolute mean power increase for AWT1 ($p = .004$), AWT2 ($p = 0.005$), and AWT3 ($p < .001$) in the CR group ($F = 13.65$, $\eta^2 = 0.85$) but in the CRCHO group ($F = 6.16$,

Table 1. Absolute (W) and relative (W/kg) mean power values (mean ± SD) for AWT in CR, CRCHO and CON groups pre- and post-loading.

Group	Baseline				Post-loading			
	AWT1	AWT2	AWT3	AWT_{all}	AWT1	AWT2	AWT3	AWT_{all}
CR								
AMP	608±116	571±94	506±85	562±94	632*±95	598*±83	549*±93	593*±86
RMP	8.32±0.74	7.85±0.64	7.00±0.99	7.72±0.72	8.60±0.49	8.17±0.74	7.52*±1.09	8.10*±0.73
CRCHO								
AMP	603±55	555±51	504±47	554±49	606±39	574±31	533*±39	571*±34
RMP	8.53±1.10	7.87±1.15	7.15±1.07	7.85±1.09	8.45±0.87	8.01±0.93	7.43*±0.91	7.96±0.88
CON								
AMP	651±72	616±81	564±106	610±85	665±91	615±83	567±103	615±89
RMP	9.07±1.19	8.56±1.08	7.83±1.33	8.49±1.16	9.24±1.59	8.52±1.06	7.84±1.31	8.53±1.27

* significant difference compared to baseline condition. Values shown are mean ± SD.
AMP (absolute mean power).
RMP (relative mean power).

η^2=0.72) only for AWT3 (p =.001). No statistically significant differences were found in the control group for any AWT. No significant interactions were detected between groups (Table 1).

Relative mean power

A main effect of time was found for RMP_{all} (p =.008, F=40.36, η^2=0.72). Paired comparisons between the two time points (before and after supplementation) revealed significant increases in RMP_{all} in the CR group (p =.001) but not in the CRCHO (p =.329) or the CON group (p =.676).

When each AWT was analysed individually, a main effect of time was found for relative mean power (p =.000). Paired comparisons revealed a significant relative mean power increase for AWT3 both in the CR (p <.001, F=10.21, η^2=0.81) and the CRCHO group (p =.015, F=4.1, η^2=0.63). No statistically significant differences were found in the control group for any AWT. No significant interactions were detected between groups (Table 2).

Peak power

Peak power was obtained within the first three seconds and declined progressively until the end of the 30 s exercise period in all AWTs independently of supplementation. No main effect of time was found either for APP_{all} (although close to significance, p =.050) or for RPP_{all} (p =.129). When analysing each AWT individually, a main effect of time was found for absolute peak power (p =.004) and relative peak power (p =.005). Paired comparisons revealed a significant absolute peak power (p =.001, F=5.24, η^2=0.67) and relative peak power (p =.004 F=4.84, η^2=0.67) increase for AWT3 in the CR group only. No differences were recorded for the CRCHO or the CON group.

Blood lactate

A significant main effect of time (p =.000, F=144.87, η^2=0.91) and a group x time interaction were found (p =.009, F=3.65, η^2=0.36). Paired comparisons between the two time points (before

Table 2. Absolute (W) and relative (W/kg) peak power values (mean ± SD) for AWT in CR, CRCHO and CON groups pre- and post-loading.

Group	Baseline				Post-loading			
	AWT1	**AWT2**	**AWT3**	**AWT_{all}**	**AWT1**	**AWT2**	**AWT3**	**AWT_{all}**
CR								
APP	1027±313	971±248	798±150	932±231	1017±222	1053±283	956*±233	1009±238
RPP	13.9±2.97	13.14±1.89	10.87±0.85	12.62±2.03	13.71±1.72	14.18±2.78	12.9*±2.09	13.6±2.07
CRCHO								
APP	969±177	922±178	806±133	899±154	915±137	1003±88	889±71	936±56
RPP	13.582.07	12.94±2.28	11.36±2.08	12.98±1.19	12.72±2.34	13.88±0.62	12.38±1.57	13.6±2.07
CON								
APP	1299±221	1249±163	1158±193	1235±171	1291±213	1242±156	1249±163	1227±
RPP	18.07±3.51	17.30±2.03	16.08±3.02	17.17±2.59	17.85±3.28	17.152.03	15.88±3.27	16.97±2.71

* significant difference compared to baseline condition. Values shown are mean ± SD.
APP (absolute peak power).
RPP (relative peak power).

Table 3. Blood lactate (mean ± SD) concentration ($mmol.L^{-1}$) during baseline and post-loading condition in CR, CRCHO and CON groups pre- and post-loading.

Group	Baseline					Post-loading				
	LR	**L1**	**L2**	**L3**	**LF**	**LR**	**L1**	**L2**	**L3**	**LF**
CR	0.84	6.38	10.72	12.68	13.26	0.83	4.13*	9.18	11.99	13.41
± *SD*	0.2	1.9	2.3	2.7	3.0	0.1	1.0	1.2	2.2	2.4
CRCHO	0.82	5.72	11.72	15.02	15.72	0.58	3.93	7.35*	9.73*	10.61*
± *SD*	0.2	2.6	2.9	3.5	2.2	0.1	1.8	1.9	2.1	1.3
CON	0.96	4.69	10.29	12.57	14.45	1.16	5.66	12.02	13.52	14.24
± *SD*	0.06	0.94	1.15	2.01	2.31	0.49	1.76	2.16	2.28	2.88

* significant difference compared to baseline condition. Values shown are mean ± SD.

and after supplementation) revealed for the CR group a significant reduction in L1 blood lactate values ($p = .002$), and for the CRCHO group a significant reduction in L2 ($p = .002$), L3 ($p = .004$) and LF ($p = .001$) blood lactate values. No differences were recorded for the CON group (Table 3).

DISCUSSION

The findings of this study suggest that the ingestion of carbohydrates while performing an acute creating loading regimen does not result in any additional benefit for AWT performance compared to acute CR loading alone in physically active participants. On the contrary, the group that ingested Cr along with CHO demonstrated during the post-loading testing performance improvement in fewer performance indices (AMP AWT3, AMP_{all}, RPP AWT3) compared to the group that ingested CR only (AMP AWT1, AMP AWT2, AMP AWT3, AMP_{all}, APP AWT3, RPP AWT3, RMP_{all}).

The combined creatine and carbohydrate loading regimen prescribed in the present study has been shown to result in a 60% greater increase of muscle total creatine content (TCr) compared to the one produced following Cr loading alone [9]. Since a positive relationship exists between the magnitude of muscle TCr increase and the magnitude of performance enhancement in repeated bouts of maximal exercise [6, 7], it was expected that the particular regimen would result in a relatively large performance enhancement. However, since no measures of muscle or urinary creatine were performed, possible physiological or metabolic explanations for these findings are only speculative. Nonetheless, it is plausible that the gain in body mass that accompanies a Cr loading regimen indicates the extent of muscle creatine uptake [26] and suggests compliance with and response to the regimen. The CRCHO group showed a significant 1.1 kg increase in body mass, while the CR group showed a significant 0.7 kg increase. Increases in body mass following Cr supplementation have been attributed to creatine-stimulated water retention and an increase in total body water [26]. The additional gain in mass for the CRCHO group, however, could also be associated with the high quantity of carbohydrates ingested. The participants in the CRCHO group consumed 500 ml of an energy drink (calorific value according to manufacturer of 350 kcal) 5 times per day for 4 days. This corresponds to 10,000 ml of liquid, 2,000 g of simple sugars and 7,000 kcal. Taking into consideration that for each gram of muscle glycogen an additional 2.7 g of water are stored, [27] this could explain the extra gain in body mass observed in the CRCHO group. The same pattern of pronounced increase in body mass of subjects consuming Cr along with CHO was also reported by Green et al. [9] and Theodorou et al. [14], who also reported no performance advantage gained from the addition of carbohydrates to a creatine loading regimen in a group of high-level swimmers.

Following supplementation, blood lactate accumulation was lower in both groups. It is documented that the increased concentration of Cr and subsequently of PCr attenuates ATP degradation during high-intensity muscular activity [28]. This is likely to be a result of an increased rate of ATP resynthesis from ADP through increased availability of PCr as an energy source [29]. This would decrease the usual dependence on anaerobic glycolysis for resynthesis of ATP, thus delaying the accumulation of lactate and H^+ associated with maximal rates of glycolysis, allowing the muscle to generate a high force for an extended time. In a recent study, Rosche et al. [30] reported that Cr supplementation in rats spared the muscle glycogen content of the gastrocnemius during high-intensity intermittent exercise, resulting in lower blood lactate concentrations. However, in the present study a novel finding was that this lactate decrease was more pronounced only in CRCHO. One possible explanation for this response may be related to a greater Cr uptake by the muscle due to the combined creatine and carbohydrate supplementation, as reported in the literature [9 10]. In that case, the delay in the utilisation of anaerobic glycolysis as an energy pathway for ATP resynthesis may have been even further prolonged due to the enhanced muscle TCr pool, thus resulting in even lower lactate accumulation. However, this physiological advantage was not accompanied by a corresponding increase in performance. In the authors' opinion these changes in power-to-weight ratio may have implications that may or may not be offset by the concurrent ergogenic gain from carbohydrate and creatine. Although the AWT is a non-weight-bearing exercise, this extra gain in mass may make the athlete feel "too heavy" and uncomfortable and actually negate the potential benefits to be derived from the higher CR uptake. For instance, the improvement recorded for AMP_{all} for CRCHO following supplementation was diminished when mean power was expressed in values relative to body mass. Body fat and total body water measurements could offer further insight, but the lack of these measurements is a limitation of the current study. Another possible explanation could be related to palatability issues associated with the amount of carbohydrates consumed, causing gastrointestinal discomfort [9, 14] which offsets the beneficial effects of the insulin response to Cr uptake. As a result, several supplemental interventions have been suggested in order to enhance pancreatic insulin release and at the same time minimise palatability discomforts associated with the ingestion of a large quantity of simple sugars. In this respect, some investigators [12, 31 32] have proposed the consumption of Cr in conjunction with protein, amino acids and carbohydrates or the co-ingestion of Cr with α-lipoic acid and a small amount of sucrose [33]. Unfortunately, since the feeding protocols applied in those studies were not accompanied by subsequent performance assessment, no direct comparisons can be made.

CONCLUSIONS

In conclusion, this study showed that a 4-day period of Cr supplementation with a dose of 25 g per day produced a significant improvement in anaerobic performance during intermittent AWTs. However, the execution of the acute creatine loading (25 g of $Cr.day^{-1}$ for 4 days) along with consumption of CHO (following each 5 g Cr dose) did not further improve AWT performance. The only additional effect recorded due to the combined creatine and carbo-

hydrate ingestion was a significant decrease in blood lactate production during AWT performance. These findings suggest that the ingestion of creatine in combination with carbohydrates may lead to decreased provision of energy via anaerobic glycolysis, compared to simple creatine ingestion, and lower blood lactate accumulation. Further investigation is needed on the reasons that this advantage in energy substrate availability is not accompanied by additional improvement in performance. This could mean investigation of alternative insulin secretagogue feeding regimens not producing negative effects on body mass and/or exercise protocols benefiting from them.

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