Creatine Supplementation May Attenuate the Decrement in Exercise Performance during Low Carbohydrate Diets in Recreationally Trained Individuals

Original Research

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Open Access

Published: July 22, 2024

Journal of Exercise and Nutrition: *2024, Volume 7 (Issue 1): 11*

ISSN: 2640-2572

Abstract

Introduction: Low carbohydrate (L-CHO) diets may be an effective means for weight loss; however, these L-CHO diets often result in decreases in exercise performance during high-intensity, interval exercise test (HIIET).

Methods: Nineteen, healthy, recreationally active adults participated in this study. Subjects were assigned to one of three groups: control (CON), L-CHO diet w/ placebo (L-CHO), or L-CHO diet w/ creatine supplementation (L-CHO+Cr). Subjects performed HIIET to fatigue at 90% peak power output (PPO) with a 1:1 work-to-recovery ratio of 30 s. Dietary intervention consisted of <30% total intake of carbohydrates, while creatine supplementation consisted of a standard loading dose (20 g/day) or placebo (5 g/day).

Results: There was no statistically significant difference in HIIET performance (# of intervals completed) in the L-CHO+Cr group (Pre-: 28.9 ± 18.6; Post-: 32.4 ± 18.3, $p > 0.05$). When expressed as a % change from pre-dietary intervention, L-CHO resulted in the greatest decrease in HIIET performance (L-CHO: -35 ± 14; CON: 12 ± 10; L-CHO+Cr: 31 ± 11 % change from pre-, $p < 0.05$).

Conclusions: The addition of a standard loading dose of creatine during a L-CHO diet may help to attenuate the decrement in HIIET performance.

Key Words: high-intensity exercise, exercise tolerance, repeated-bout

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Introduction

For more than a century, there has been an interest in how dietary modifications influence exercise performance and tolerance. One area that has garnered much interest is the consumption of carbohydrates (CHO) and how the resulting glycogen availability can impact exercise performance and tolerance[1-4]. As such, there is a large body of research examining the influence of a high-carbohydrate diet compared to a low-carbohydrate (L-CHO) diet on exercise performance[1-4]. Exercise performance may be negatively impacted by an L-CHO diet[1-4], yet others have demonstrated that, following four weeks of a L-CHO diet, there were no adverse effects on performance during a high intensity bout compared to a habitual mixed diet[5]. L-CHO diets have been known to decrease resting glucose and insulin levels, and increase fatty acid oxidation rates, which may be advantageous to

performance of prolonged submaximal endurance exercise[6-7]. Even the leanest athletes still possess an abundance of stored lipid energy; exercise of long duration (i.e. > 90 minutes) relies primarily on oxidative metabolism in order to sustain exercise performance, yet many still "hit the wall" as a result of glycogen depletion[1,8-9], demonstrating a reliance on carbohydrates as fuel despite ample fatty acid availability.

Consumption of a L-CHO/High Fat diet for longer than three days results in an alteration in gene expression and enzyme function that favors oxidative pathways, particularly that of fatty-acid oxidation[6,8-10]. This shift results in a fat-adapted state, both at rest and during exercise, as exhibited by mitochondrial biogenesis, an increased number in fatty acid transporters (FATCD36), and a down-regulation in the activity of key glycolytic enzymes, such as glycogen phosphorylase (PHOS), phosphofructokinase (PFK), and pyruvate dehydrogenase (PDH)[8-9]. However, despite this fat adapted state, exercise performance may still be negatively impacted, particularly early, in a L-CHO diet and during high intensity exercise[1,3,10-11].

In the face of reduced intramuscular glycogen stores, greater energetic demand may be placed upon the phosphocreatine (PCr) system[2,12]. While the PCr energy system can sustain intense exercise for only a short time (~7 seconds), it may aid in the postponement of fatigue associated with intense exercise in the face of a reduced reliance on glycolysis[13-16]. Performance of high intensity exercise on a L-CHO diet is associated with a greater accumulation of inorganic phosphate (P_i), which is considered a primary cause of fatigue[2,17]. Using P-magnetic resonance spectroscopy (P-MRS), Larson et al.[2] demonstrated a greater decrease in PCr in subjects following a high fat (i.e. L-CHO) diet when compared to those following a H-CHO diet. This was attributed to the PCr/P_i ratio, or rather the more rapid decline of this ratio signifying an accumulation of P_i with a subsequent decrement of intramuscular PCr content[2].

The PCr energy system consumes a proton (H^+) while generating ATP, which may help to delay the acidosis associated with high-intensity exercise while on a L-CHO diet[18-19]. This energy system's capacity for ATP production and recovery may be enhanced by both high-intensity interval exercise and the consumption of a creatine supplement[13,16,19]. Considering its buffering effects as well as increased energy production capacity, it may be possible to prolong high intensity interval exercise performance using a creatine loading protocol while consuming a L-CHO diet. For an individual to benefit from specific dietary and training protocols as well as enhance exercise performance, it is necessary that exercise intensities be maintained[4]. Therefore, if an individual can be metabolically primed to favor fatty acid oxidation by way of a L-CHO diet, they might be able to extend time to exhaustion and thereby delay the onset of fatigue during prolonged exercise bouts. The purpose of this study was to examine the effect of a creatine supplement on repetitive high-intensity exercise performance while on a short-term L-CHO diet. It was hypothesized that the addition of a creatine supplement while on a L-CHO diet would attenuate the performance decrements compared to a L-CHO diet only.

Methods

Participants

This study was approved by the Institutional Review Board for Human Subjects at the University of Toledo and was conducted in accordance with the Declaration of Helsinki. All subjects were fully informed of the experimental procedures and any possible risks or benefits associated with this study before providing their written consent to participate. Nineteen healthy, recreationally active subjects (male = 8, female = 11) between the ages of 18 and 45 years volunteered for this study. Any individual who self-reported a history of metabolic, pulmonary, cardiovascular disorder, diabetes, hypertension, were currently smoking or quit smoking in the last twelve months, suffered any orthopedic-related injuries affecting their ability to perform cycling exercise, or were currently pregnant or nursing was excluded.

Experimental Procedures

This study utilized a single-blind, random distribution experimental design. Subjects were assigned to one of three groups: control (CON), L-CHO diet and placebo (L-CHO), or L-CHO diet and creatine supplementation (L-CHO+Cr). Subjects reported on four separate visits within a two-week timeframe to complete three exercise sessions (two pre-dietary intervention and one post-dietary intervention) and a familiarization session where the investigator provided specific instructions on the L-CHO diet, how to keep an accurate food and exercise log, and instructions on how to consume the supplement. Each subject was instructed to refrain from any strenuous physical activity 24 hours prior to each exercise session and directed to maintain their current exercise habits for the duration of the investigation. The study outline can be found in Table 1.

Table 1. Outline of methods.

DAY 1		DAY 2		DAY 3	DAY 4-13	DAY 14
Pre-Diet Log directions given	Minimum of 4 days	Pre-Diet Log reviewed for accuracy and collected for analysis	Minimum of 4 days	Group Assignment • L-CHO (<30% CHO + placebo) • L-CHO+Cr (<30% CHO + CM) • CON (no intervention)	Subject Check-ins for Diet & Supplement Compliance	Post-Diet Log reviewed for accuracy and collected for analysis
Baseline Physiological Data Collected				Supplement Distribution • Placebo (4 g/d split into 1 g doses) • CM (20 g/d split into 5 g doses)		Post-Intervention Physiological Data Collected
Pre-Intervention HIIET						Post-Intervention HIEET

Pre-Dietary Intervention

Standard physiological measurements were recorded including age (years), height (cm), weight (kg), resting heart rate (bpm), resting blood pressure (mmHg), and body composition (e.g. percent body fat, BF). Resting heart rate and blood pressure were measured using an automated blood pressure cuff (Omron Digital Blood Pressure Monitor HEM-907XL, Omron Healthcare, Lake Forest, IL). Body composition was assessed using an air displacement plethysmography technique (BodPod, COSMED, Chicago, IL).

Subjects then underwent a progressive incremental ramp exercise test to volitional fatigue on an electronically braked cycle ergometer (Lode, Groningen, the Netherlands) with pulmonary gas exchange measured (VMax Carefusion, BD Worldwide, USA) continuously. The ramp exercise test consisted of a 4-minute baseline (20 W) followed by a progressive increase in exercise intensity (25 W/min) until the subjects reached volitional fatigue. Subjects were instructed to maintain a pedaling cadence of 80-100 revolutions per minute (rpm) during the test. The highest VO_2 averaged over a 10-second interval was taken as VO_{2peak}. Additionally, peak power output (PPO) was determined from the ramp protocol, 90% of PPO was utilized for the high-intensity interval exercise test (HIIET), which was performed before and after the 10-day dietary intervention.

During the second visit, all subjects completed a HIIET. During the HIIET, work rate and pedal cadence were monitored and recorded using Lab Chart 7 (PowerLab, ADInstruments, San Francisco, CA), and heart rate was recorded using an electrocardiograph (Schiller AT-10, Schiller, Switzerland). The HIIET consisted of a 4-minute warm-up (20 W), followed by repeated intervals, which consisted of a 30-second high-intensity interval (90% PPO), followed by 30-seconds of unloaded cycling as an active recovery interval. Each subject was instructed to perform as many intervals as possible, maintaining a pedal cadence of 80-100 rpm. The endpoint of the HIIET was defined as the point when the subject was no longer able to complete an entire exercise interval from onset to end at 80-100 rpm. The interval duration was established to adequately diminish the high energy phosphate systems during exercise, and to prevent the full recovery of these energy stores during the recovery period[19].

Dietary Intervention and Supplementation

Subjects assigned to either of the L-CHO intervention groups (L-CHO+Cr or L-CHO) were required to adhere to a CHO-restricted diet for 10 days, which consisted of consuming < 30% of total calories from CHO. Subjects were not controlled for total caloric intake; they were asked to maintain as closely as possible to their normal calories or food quantities. Any subject who changed their caloric intake by 550 kcals (increase or decrease) was excluded from data analysis. Subjects were also not directed to meet any particular protein or fat percentage intake. A list of foods low in CHO content and foods to avoid were provided to each of the subjects. In addition, a dietary guide offering suggestions on how best to adhere to the dietary intervention, which included upper limit definitions for food labels (i.e. <10g CHO per food item) was provided. Subjects assigned to the CON group were asked to maintain their current diet.

Subjects in the L-CHO group received a placebo (NOW® Foods) and subjects in the L-CHO+Cr group received a creatine supplement (creatine monohydrate (CM), NOW® Foods). Supplements were provided in premeasured

individual serving vitals (1g = placebo, 4g = creatine). Subjects were instructed to dissolve each premeasured serving with eight ounces of tepid water and to consume a total of five servings each day (5g/day of placebo, 20g/day of creatine) with approximately two hours between servings for 10 days[20-22]. The subjects were all contacted a minimum of six times over the course of the 10-day intervention period by the investigator to offer support and answer any questions.

Post-Dietary Intervention
Ten days following the first HIIET, all subjects completed anthropometric measurements and the HIIET again. All procedures were completed following the same methods as the pre-dietary intervention.

Dietary Analysis
All subjects were instructed to complete a nutrition log for three days prior to the dietary intervention, which was considered baseline, as well as during the 10-day intervention period. Dietary intake data, as recorded by the subject via the MyFitnessPal app, was analyzed for average caloric and macronutrient intake using Nutritionist Pro (Axxya Systems, San Bruno, CA) under the guidance of a registered dietitian. The dietary data was entered in conjunction with subjects' gender, height, weight, and year of birth. If the brand of food recorded in the food log was not listed in Nutritionist Pro, an internet search was performed to find the weight, calories, and macronutrient content. After all dietary intake data was entered, the specified time frame (i.e. pre-dietary and dietary intervention periods) were analyzed for macronutrient content (%CHO, %Fat, %Protein).

Statistical Analysis
All data were normally distributed as determined by Shapiro-Wilk test. The HIIET (number of intervals completed) and all dietary data (%CHO, %Fat, %Protein, Total kcals) were analyzed using a two-way analysis of variance (ANOVA). One-way ANOVAs were used to compare pre-dietary intervention VO_{2peak}, body weight, and percent body fat, as well as change in percent BF, and change in weight (pre-to-post). Due to sex differences, weight and percent body fat were expressed as percent change from pre-dietary intervention (%Wt, %BF). Additionally, a % change from pre-dietary intervention was calculated for the number of intervals completed and analyzed using a one-way ANOVA. Based on the results of the ANOVA, a significant F ratio was further analyzed using a Tukey post-hoc analysis. Significance was set a priori at $p \leq 0.05$. All statistical analyses were conducted using SigmaPlot 14.0 (Systat Software, San Jose, CA). Unless specified otherwise, all data are presented as the mean ± standard deviation (SD). Effect size (ES) was interpreted where <0.2= minimal, 0.2-0.5= small, 0.5-0.8= moderate, and >0.8= large.

Results
Subject anthropometric characteristics are presented in Table 2. There were no significant differences in body weight ($p = 0.88$), percent body fat ($p = 0.83$), or VO_{2peak} ($p = 0.86$) amongst groups pre-dietary intervention.

Table 2. Baseline subject characteristics.

N = 19 (8 male; 11 female)	**CON (n = 6)**	**L-CHO (n = 7)**	**L-CHO + Cr (n =6)**
Age (years)	33 ± 9	25 ± 6	25 ± 5
Height (cm)	169.2 ± 7.8	171.4 ± 8.1	165.7 ± 5.5
Weight (kg)	73.2 ± 21.0	68.4 ± 9.0	73.1 ± 19.2
Body Fat % (females)	28.7 ± 1.7	32.0 ± 6.6	33.5 ± 8.3
Body Fat % (males)	25.9 ± 1.3	16.0 ± 9.5	20.7 ± 6.4
Systolic BP (mmHg)	117 ± 15	115 ± 9	125 ± 17
Diastolic BP (mmHg)	74 ± 6	74 ± 7	77 ± 16
Resting HR (bpm)	62 ± 10	65 ± 9	63 ± 10
Resting RER	0.76 ± 0.03	0.78 ± 0.03	0.80 ± 0.03
Exercise RER	1.02 ± 0.06	1.03 ± 0.04	1.04 ± 0.05
VO_{2peak} (mL/kg/min)	35.4 ± 3.2	36.9 ± 5.8	36.2 ± 5.9
Peak HR (bpm)	180 ± 9	188 ± 16	184 ± 5

Data are Means ± SD; VO_{2peak}, peak oxygen consumption, CON, control; L-CHO, low carbohydrate + placebo; L-CHO+Cr, low carbohydrate + creatine.

Results of the ANOVA for HIIET revealed no significant interaction ($p = 0.08$) for condition by time. The number of intervals completed pre-intervention (37.1 ± 15.1) was not significantly different from the number of intervals completed post-intervention (22.1 ± 5.8) in the L-CHO (ES = 0.99). No significant differences were found within the

L-CHO+Cr (pre- = 28.9 ± 18.6, post- = 32.4 ± 18.3, ES = 0.19) or CON (pre- = 33.2 ± 10.1, post- = 36.5 ± 9.3, ES = 0.33) for HIIET pre- and post-intervention. When expressed as a % change from pre-dietary intervention, the one-way ANOVA reported a significant difference between groups. Further post-hoc testing revealed that the L-CHO condition resulted in a significantly lower change from pre- (-36 ± 14%) compared to CON (12 ± 10%) and L-CHO + Cr (31 ± 11%, $p < 0.001$).

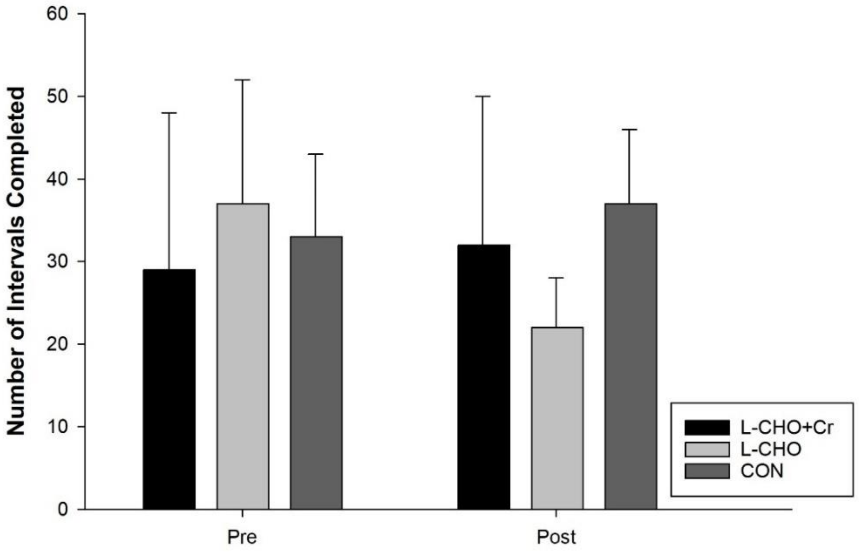

Figure 1. Total number of completed intervals.

Body Composition

The results of the one-way ANOVA revealed a significant difference between the L-CHO+Cr ($p < 0.001$, ES = 2.47) and L-CHO ($p < 0.001$, ES = 2.56) compared to the CON for %Wt. The %BF were also significantly different between L-CHO+Cr ($p = 0.002$, ES =1.75) and L-CHO ($p = 0.001$, ES = 2.35) compared to CON for %BF.

Table 3. Body composition and total energy intake pre- and post-dietary intervention.

	Weight – Pre (kg)	Weight – Post (kg)	BF – Pre (%)	BF – Post (%)	Kcals – Pre	Kcals – Post
CON (n = 6)	73.2 ± 21.0	73.1 ± 20.7	27.3 ± 2.0	27.6 ± 2.4	1456 ± 401	1558 ± 622
CHO (n = 7)	68.4 ± 9.0	66.5 ± 8.5*	25.1 ± 11.1	23.9 ± 11.1*	1387 ± 371	1437 ± 343
L-CHO + Cr (n = 6)	73.1 ± 19.2	70.9 ± 18.1*	29.2 ± 9.7	27.5 ± 8.8*	1565 ± 338	1240 ± 326*

Data are Means ± SD; BF, body fat, *, indicates significant difference from pre- values, $p < 0.05$

Dietary Data

Results of the two-way ANOVA for %CHO revealed significant main effects for condition and time, as well as a significant interaction for condition by time. Post-hoc analysis revealed that there were no significant differences in %CHO between groups pre-dietary intervention. CON (49.3 ± 5.5 % total kcals) resulted in a great %CHO during the dietary intervention compared to both L-CHO (17.5 ± 4.1 % total kcals) and L-CHO+Cr (21.0 ± 8.8 % total kcals). L-CHO resulted in a lower %CHO during the dietary intervention compared to pre- (42.5 ± 6.4 % total kcals), representing a 25.0 ± 5.7 % decrease from pre-dietary intervention. L-CHO+Cr resulted in a lower %CHO during the dietary intervention compared to pre- (42.8 ± 6.6 % total kcals), representing a 2.7 ± 9.7 % decrease from pre-dietary intervention. The CON result in no difference in %CHO pre- to post- ($p = 0.71$).

Results of the two-way ANOVA for %PRO revealed significant main effects for condition and time, as well as a significant interaction for condition by time. Post-hoc analysis revealed that there were no significant differences in %PRO between groups pre-dietary intervention. L-CHO (32.9 ± 4.0 % total kcals) and L-CHO+Cr (29.9 ± 4.4 % total kcals) resulted in a great %PRO during the dietary intervention compared to CON (14.3 ± 1.5 % total kcals).

CHO resulted in a higher %PRO during the dietary intervention compared to pre- (17.7 ± 4.9 % total kcals), an increase of 15.2 ± 6.3 % from pre-dietary intervention. L-CHO+Cr resulted in a higher %PRO during the dietary intervention compared to pre- (18.2 ± 3.3 % total kcals), an increase of 12.5 ± 6.6 % from pre-dietary intervention. The CON result in no difference in %PRO pre- to post- ($p = 0.49$).

Results of the two-way ANOVA for %Fat revealed significant main effects for condition and time. Post-hoc analysis revealed that there were no significant differences in %Fat between groups pre-dietary intervention. L-CHO (47.3 ± 6.3 % total kcals) and L-CHO+Cr (48.7 ± 7.9 % total kcals) resulted in a higher %Fat during the dietary intervention compared to CON (35.5 ± 4.7 % total kcals). L-CHO resulted in a higher %Fat during the dietary intervention compared to pre- (37.3 ± 7.7 % total kcals), 10.0 ± 7.5 % increase from pre-dietary intervention. L-CHO+Cr resulted in a higher %Fat during the dietary intervention compared to pre- (37.3 ± 4.7 % total kcals), 10.5 ± 6.2 % increase from pre-dietary intervention. The CON result in no difference in %Fat pre- to post- ($p = 0.47$).

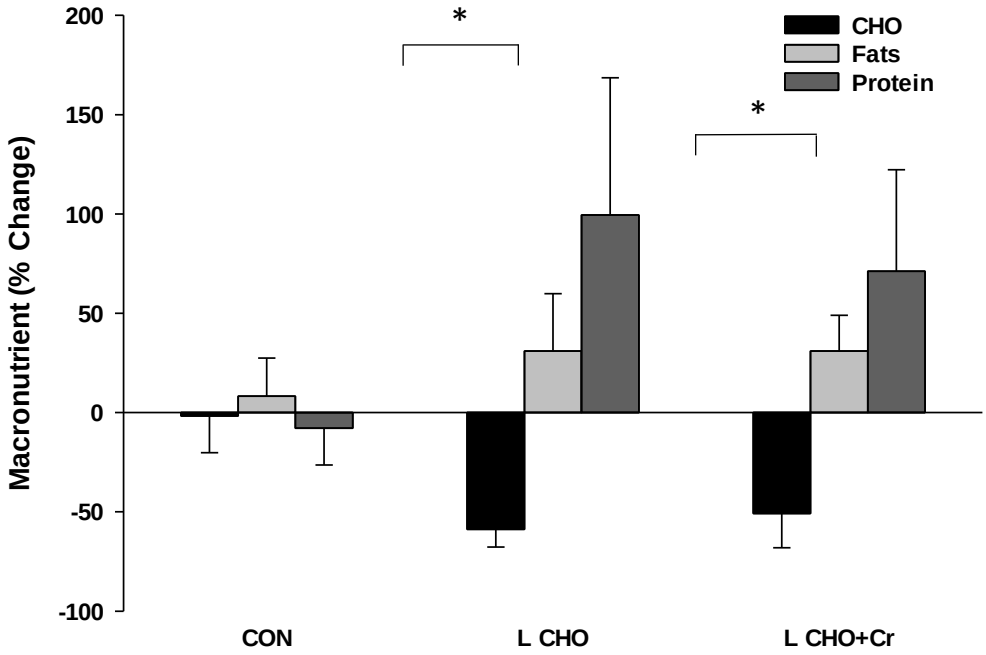

Figure 2. Contribution of macronutrients to total energy intake, expressed as percent (%) change from baseline dietary logs compared to the dietary logs recorded during the intervention period. *, indicates significant difference between the change in macronutrient intake compared to baseline intake within each group.

Discussion

The aim of the study was to determine whether a creatine supplement was able to attenuate the decrements in exercise performance while on a L-CHO diet. The results of the present study indicate that consuming a standard loading dose (20g/day for 10 days) of creatine while on a L-CHO diet (<30% CHO) modulated the decrements in repetitive high-intensity exercise performance commonly experienced with a reduction in CHO consumption. The results of the present study support our initial hypothesis, as the L-CHO+Cr demonstrated a 30% increase in performance on average pre- to post-intervention, which was not statistically different from CON, which showed a 14% increase in performance on average pre- to post-intervention. Additionally, the L-CHO resulted in an approximately 40% decrease in performance on average pre- to post-, which was statistically significant. Taken together, these results may provide evidence to suggest that the creatine supplementation implemented in this investigation was successful in attenuating the decrease in anaerobic performance that is common in L-CHO diets.

The attenuation in exercise performance observed in the current study is evidenced by the decrease in HIIET performance in the L-CHO group pre- vs. post-intervention (~40% reduction), with the concurrent maintenance or

increase in performance exhibited by the L-CHO+Cr group (~30% increase). Although these results demonstrate positive trends, the lack of statistical significance in raw values, or intervals completed in the HIIET, suggests an absence of conclusiveness.

Speculatively, these results may be closely related to maintenance of the PCr/P_i ratio[2]. It is generally accepted that peripheral fatigue during high intensity exercise occurs as a result of the accumulation of toxic metabolites and/or depletion of energy stores[2,19,23]. However, there is evidence to suggest that the accumulation of P_i and the resulting fall in PCr/P_i ratio plays a larger role in peripheral fatigue leading to a decreased performance[2]. The accumulation of P_i may impair force production directly by the inhibition of cross-bridge function[23-24]. It may also indirectly impair force production by causing a reduction in myofibrillar Ca^{2+} sensitivity and sarcoplasmic reticular Ca^{2+} handling[23-24].

Conversely, it is also possible that an increase in intracellular PCr stores may have impacted the oxygen deficit, the reduction of which may increase time to fatigue during high intensity exercise[25]. The ability of creatine supplementation to enhance repeated high intensity exercise performance, while following a normative diet, has been demonstrated previously[14-15,22]. The increase in PCr, as achieved through creatine supplementation, may act to postpone peripheral fatigue by delaying the accumulation of ADP and P_i, which are activators of glycolysis[14]. Theoretically, if intracellular creatine stores can be increased, there could be an extension of the high phosphate energy systems during brief intense exercise[26]. The advantage of the PCr system is that energy can be produced quickly and, in contrast to anaerobic glycolysis where lactate is produced, the proton is buffered from this reaction, thereby delaying the accumulation of toxic metabolites that would contribute to peripheral fatigue[26]. Utilizing a creatine supplement, and subsequently maximizing the potential of the PCr energy system, may allow individuals to train more intensely, which can ultimately lead to greater increases in maximal strength and power, critical power, and repeated-bout high-intensity exercise performance[14-15,22]. In the present study, the L-CHO+Cr resulted in no statistically significant difference between pre- and post-HIIET, whereas the L-CHO resulted in a significant decrease in intervals completed pre- to post-. These results may further support to the aforementioned hypothesis that bolstering the PCr system may delay peripheral fatigue during short-bouts of high intensity exercise, particularly in the face of reduced glycogen stores associated with a L-CHO diet. However, in the absence of any direct biochemical or molecular measures, the proposed mechanisms of action that may have played a role in the performance outcomes of the present study are merely speculative.

Consumption of a L-CHO diet for >3 days is associated with metabolic and cellular adaptations that contribute towards increased lipid utilization both at rest and during submaximal exercise[6,9-10], yet some research suggests it may also increase the lipid contribution to intense exercise efforts (>60% VO_{2max})[7,27]. This metabolic shift, or fat adaptation, is also suggested to result in greater body fat loss within the first six months of a reduced calorie diet, as compared to an isocaloric low-fat diet[28], making it a viable dietary option for individuals seeking such changes in body composition. Additionally, it is generally accepted that high intensity exercise is integral to both body fat loss and improvements in markers of exercise performance (i.e. VO_{2peak}, lactate threshold)[29-30], making it a valuable method for improving exercise performance as well as body composition. Thus, it is paramount for optimal training and body composition to maintain intensity and duration while consuming a L-CHO diet. The results of the present study suggest that a creatine supplement may aid in bridging the performance gap between high intensity training and a L-CHO diet.

The results of the present study coincide with similar studies that examined very L-CHO diets and exercise performance, while also monitoring changes to body mass and composition[1,5]. While alterations to body mass and composition were not the primary aim in either the previous studies or the present study, changes in total body mass (%Wt) and body fat (%BF) were evident (Table 3), with the L-CHO groups losing more comparatively to other groups[1,5]. While decreases in body mass are attributable to decreased energy intake, it is theoretically possible that greater decreases in body fat are evident as a result of reduced CHO intake and increased lipid utilization associated with a L-CHO diet[28].

Dietary Considerations

Although both dietary intervention groups adhered to the CHO restriction and consumed a high-fat diet (>45% fat), the greatest observed macronutrient increase was protein. Both groups increased their protein consumption during the dietary intervention, with the L-CHO+Cr group demonstrating a 71.2% increase and L-CHO group increasing by 99.5% above baseline. Subjects were not specifically directed to increase fat or protein more than the other, but were permitted to select foods freely, as long as they kept their CHO consumption to <30% total intake. It is therefore plausible that the increase in dietary protein consumption aided in the maintenance of lean body mass, allowing for the greater percent change in body fat exhibited in the intervention groups compared to CON.

Potential Limitations

Although subjects consumed a typical loading dose of creatine (20g/day for 10 days), they were not tested for increased intramuscular creatine content. However, previous studies have demonstrated, using muscle biopsy, that a loading dose of 20g/day for five days is sufficient to increase intramuscular stores of PCr[20-21]. Subjects were prescreened to ensure they were not already consuming a creatine supplement, and self-reported compliance with supplementation was accepted. The results of the pre- to post-intervention HIIET in the L-CHO+Cr group suggests compliance with supplementation, although this cannot be definitively confirmed.

Subjects were asked to consume <30% of their total energy intake from carbohydrates, and provided a 3-day baseline diet that was analyzed to ensure they were not already consuming a CHO-restricted diet. They were permitted to eat *ad libitum* to an effort to improve compliance to the restriction in carbohydrates. While it is possible that some decrement in performance is attributable to lower total energy intake, it is unlikely as the only group to significantly decrease their total energy intake was the L-CHO+Cr group – who also demonstrated a 30% increase in performance. Further, dietary logs were accepted as self-reported through the MyFitnessPal app, dietary analysis was conducted through Nutritionist Pro under the guidance of a registered dietitian, improving the accuracy of reported nutrient values. Lastly, any subject who did not adhere well to the guidelines (i.e. changed total energy intake too drastically [± 550 kcal/d] or consumed <30% CHO) were excluded from the study.

While the present investigation provides evidence for promising trends for using creatine supplementation to attenuate the decrease in exercise performance associated with a L-CHO diet, the statistical power should be considered. Using the most conservative effect size ($d = 0.6$) indicated that a sample size of 30 subjects would be sufficient when $\alpha = 0.05$ and $\beta = 0.80$ (Power calculations were performed using the G*Power software). Only 19 participants were recruited for this investigation and as such, there may not be sufficient power to detect significant differences across groups. Further investigations with a larger subject pool are warranted to provide for concrete evidence for these assertions. Additionally, long-term investigations on L-CHO diets with creatine supplementation are necessary to confirm the durability of the findings of this investigation.

Both groups that underwent dietary intervention exhibited changes in body composition, losing both total weight and body fat. The participants were asked to maintain their caloric intake and were directed to maintain their current exercise habits. While the study intervention cannot ultimately account for the body composition changes, as caloric intake and energy expenditure was not controlled for, the performance outcomes propose compliance.

Conclusions

In conclusion, the results of this study show positive trends that support the hypothesis that creatine supplementation may attenuate decrements in repetitive high-intensity exercise performance traditionally observed following a L-CHO diet. It is possible that the addition of creatine supplementation enhanced stored PCr, which in turn may have attenuated the decrement in performance associated with HIIET while on a L-CHO diet. Thus, the addition of creatine supplementation may allow individuals to maintain exercise intensity while following a L-CHO diet, thereby providing benefits in exercise performance and improved body composition concurrently.

Acknowledgements

The study was designed by SAB and BWS; data were collected and analyzed by SAB, TRR, and EJVW; data interpretation and manuscript preparation were undertaken by SAB, TRR, EJVW, JDL, JRT, DJB, BWS, and EN. All authors approved the final version of this paper.

The study was approved by the University of Toledo Institutional Review Board for Biomedical Research and conducted in accordance with the Declaration of Helsinki. All subjects were fully informed of the experimental procedures and possible risks before providing their written consent to participate.

Guarantee of product purity and safe manufacturing processes was provided by NOW ® Foods prior to its use in this study. The authors received no outside funding nor have any potential conflict of interest in the outcome of this study.

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