Effects of Oral Creatine Supplementation on High Intensity, Intermittent Exercise Performance in Competitive Squash Players

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The purpose of this study was to determine the effects of oral creatine supplementation on high intensity, intermittent exercise performance in competitive squash players. Nine squash players (mean ± SEM $\dot{V}O_2max$ = 61.9 ± 2.1 ml · kg^{-1} · min^{-1}; body mass = 73 ± 3 kg) performed an on-court "ghosting" routine that involved 10 sets of 2 repetitions of simulated positional play, each set interspersed with 30 s passive recovery. A double blind, crossover design was utilised whereby experimental and control groups supplemented 4 times daily for 5 d with 0.075 g · kg^{-1} body mass of creatine monohydrate and maltodextrine, respectively, and a 4 wk washout period separated the crossover of treatments. The experimental group improved mean set sprint time by 3.2 ± 0.8 % over and above the changes noted for the control group (P = 0.004 and 95 % CI = 1.4 to 5.1 %). Sets 2 to 10 were completed in a significantly shorter time following creatine supplementation compared to the placebo condition (P < 0.05). In conclusion, these data support existing evidence that creatine supplementation improves high intensity, intermittent exercise performance. In addition, the present study provides new evidence that oral creatine supplementation improves exercise performance in competitive squash players.

Key words: Phosphocreatine, ergogenic aid, repetitive sprint, ghosting.

Introduction

Squash rackets is a game characterised by repeated bouts of high intensity exercise which place considerable demands on both the aerobic and anaerobic energy systems [36, 44]. Phosphocreatine (PCr) is one of the most important substrates for adenosine triphosphate (ATP) resynthesis during the high intensity exercise bouts and it is generally accepted that the development of fatigue during maximal short duration exercise is associated with the depletion of muscle PCr stores [16, 26, 30, 35]. Creatine (Cr) and PCr serve to continuously preserve intracellular ATP availability, modulate metabolism and buffer hydrogen ion accumulation during muscle contraction [21].

Athletes have used Cr supplementation in an attempt to increase the muscle PCr concentration and thereby improve exercise performance by delaying PCr depletion and the rate of ADP accumulation during maximal exercise and/or promoting PCr resynthesis during recovery. Several studies have reported improved exercise performance in healthy individuals during repeated bouts of maximal short-duration exercise following Cr supplementation [2, 5, 23].

Most studies, however, claim an ergogenic effect of Cr on the basis of laboratory based experimental protocols – few studies have examined the effects of Cr on exercise performance under realistic competitive milieu. Furthermore, there is a paucity of data regarding the effects of Cr on exercise performance in well-trained individuals, and the authors are unaware of any published research documenting the ergogenic potential of Cr supplementation for improvement in squash-specific exercise performance. The specific metabolic requirements of squash lend themselves to the study of Cr supplementation on subsequent exercise performance. Thus, the purpose of the present study was to conduct a placebo controlled, double blind crossover study to determine the effects of oral Cr supplementation on high intensity, intermittent exercise performance in competitive squash players.

Methods

Participants

Following local ethics approval and written informed consent, ten competitive squash players (9 male) of county level or above volunteered to participate in the study. One male individual did not fully adhere to the participant preparation guidelines and was therefore removed from all subsequent analyses. Descriptive characteristics of the participant group are presented in Table **1**.

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Table 1 Descriptive and physical characteristics of the participants

	Mean	SEM
Gender (M/F)	8/1	-
Age (y)	21.3	0.3
Stature (m)	1.77	0.04
Body mass (kg)	73.3	3.3
Sum of 4 skinfolds (mm)	35.0	3.9
Estimated body fat (%)	15.2	1.4
Fat mass (kg)	11.2	1.2
Fat free mass (kg)	62.2	2.8
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	4.52	0.21
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	61.9	2.1

General design

A double blind, crossover design was utilised whereby participants were randomly assigned to either an experimental (Cr) or control (placebo) group. The design was counterbalanced (i. e., an equal number of subjects started each condition) in order to eliminate an order effect. After one initial familiarisation session participants performed an on-court "ghosting" routine pre- and post-supplementation. A 4 wk washout period separated the crossover of treatments and the "ghosting" routine was repeated immediately prior to the crossover. All procedures were conducted in accordance with ethical standards of the Committee on Human Experimentation at the host institution and with the Helsinki Declaration of 1975. Fig. **1** provides a schematic representation of the study design.

Procedure

Participant preparation and testing environment

Each test was scheduled at a similar time of day (± 1 h) in order to minimise the effect of diurnal fluctuation [1]. Participants were advised not to engage in strenuous activity two days before an exercise test and not to exercise on the day of a test. Individuals were requested to maintain their normal diet in the few days preceding an exercise test, to refrain from alcohol two days before a testing session, and to avoid caffeinated beverages on a test day. Court temperature was maintained throughout the duration of the study, and participants were thoroughly familiarised with test procedures prior to data collection.

Body anthropometry

Body mass was measured on accurately calibrated electronic scales (Seca Alpha 770, Birmingham, UK) to the nearest 0.1 kg, and stature with a stadiometer (Seca 220, Birmingham, UK) recorded to the nearest 0.5 cm. Body density was estimated from the sum of four skin-fold sites based on the procedures of Durnin and Womersley [13], and estimated percentage body fat was calculated using the equation of Siri [45]. Fat free mass was calculated by subtracting fat mass from total body mass.

Maximum oxygen uptake

Participants performed a maximal incremental exercise test on a motorised treadmill (Quinton Q65, Seattle, USA) for determination of maximum oxygen uptake ($\dot{V}O_2max$). Ventilatory and pulmonary gas exchange indices were measured breath-by-breath using an automated on-line gas analysis system (Mijnhardt Oxycon Alpha, Bunnik, Holland), and $\dot{V}O_2max$ was defined as the highest value averaged over 1 min.

"Ghosting" routine

Following a standardised warm up, participants performed an on-court "ghosting" routine, which involved 10 sets of 2 repetitions, each set interspersed with 30 s passive recovery (Fig. **1**). Every repetition required participants to simulate positional play during a game of squash and involved the following fake shots: front right corner forehand drop-shot (A), front left corner backhand drop-shot (B), back left corner backhand (C), back right corner forehand (D), right forehand volley at head-height (E), and left backhand volley at head-height (F). Participants were instructed to position the racquet head over taped off areas on the court and to always place one foot within a 0.5 m square box located over the "T" between shots. The on-court set-up and order of shots are illustrated in Fig. **2**. Repetition time was measured with electronic timing gates (Eleiko Sport AB, Sweden), recovery time was measured manu-

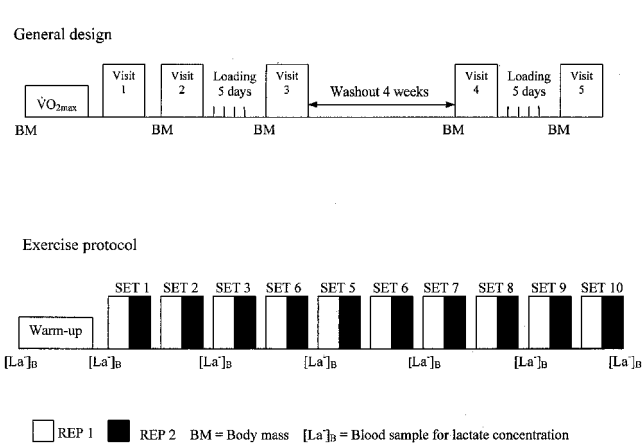

Fig. 1 General study design (upper panel) and exercise protocol (lower panel).

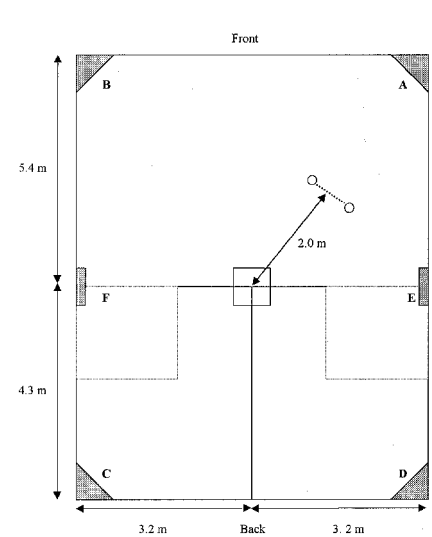

Fig. 2 Court set-up

ally with a stopwatch, and participants were instructed to complete each repetition in the shortest time possible. The test was designed to elicit a set sprint time of ~ 30 s. A fatigue index was calculated for the ghosting routine as the mean of sets 1 and 2 vs. the mean of sets 9 and 10. The within-subject coefficient of variation (CV) and intraclass correlation coefficient (ICC) for mean set time determined for the control condition separated by 5 days were 1.5% and 0.88, respectively. Heart rate (f_c) was monitored throughout each trial by telemetry (Polar Vantage NV, Finland) and data were analysed using appropriate software (Polar Precision Performance 2.0, Finland).

Blood sampling and analysis

Capillary blood was sampled from an earlobe pre- and post-warm up, after every alternate set, and 2 min post-exercise for subsequent determination of whole blood lactate concentration ($[La^-]_B$). Blood samples were obtained using a sterile lancet, collected in 100 µl heparinised capillary tubes, and pipetted into 0.5 ml micro-centrifuge tubes. The tubes were agitated, immediately stored on ice (~2 °C), and analysed in duplicate within 4 h of collection using an electrochemical analyser (YSI 2300 Stat Plus, USA).

Loading regimen

The experimental and control groups supplemented 4 times daily for 5 d with 0.075 $g \cdot kg^{-1}$ body mass of Cr monohydrate and maltodextrine, respectively. This loading regimen results in a rapid (within 20 min), marked (~1 mM increase), and sustained (~3 h) rise in plasma Cr concentration [25]. Both groups were instructed to dissolve the supplement in warm solution and ingest in combination with simple carbohydrates [19,20]. Participants were advised to refrain from caffeinated beverages [50] and allowed to exercise normally during the first few days of supplementation [25]. Subjects reported that they were unable to discriminate between the two interventions either at the end of each loading period or at the end of the study. A 4 wk washout period separated the crossover of treatments. The natural time-course of muscle Cr decay following 5 d of 20 $g \cdot d^{-1}$ loading occurs over the course of 3 to 4 weeks [27].

Adverse effects

Participants were asked to rate their perceptions of cramping, gastrointestinal distress, nausea, dizziness, and dehydration using a 4 point Likert scale (0 = not at all, 1 = mild, 2 = moderate, 3 = severe) immediately following the placebo and Cr interventions. It was impressed upon participants that the subjective ratings should be scored relative to normal sensations experienced prior to the study. In addition to the perceptual ratings, body mass was recorded following both interventions.

Data analyses

Repeated measures ANOVA was used to test for effects due to "treatment" (experimental and control), "time" (pre- and post-supplementation), "set" (1 to 10), and "repetition" (1 and 2) on each of the dependent variables (time, $[La^-]_B$, and f_c). Mauchly's sphericity test was used to check for homogeneity of variance and homogeneity of covariance. Violations of the assumption of sphericity were corrected using the Greenhouse-Geisser adjustment. The residuals from the ANOVA were checked for normality. An alpha level of 0.05 was chosen *a priori* to represent statistical significance. Planned pairwise comparisons were made with repeated measures *t*-tests and the Bonferroni adjustment was used to modify the per family type I error rate per comparison. The 95% confidence interval was calculated for the relative change in mean set time above the control condition from a *t*-distribution. Pearson product moment correlation coefficients were computed to assess the degree of relationship between the relative changes in body mass and mean sprint time following Cr supplementation. Results are expressed as mean ± standard error of the mean (SEM). All statistical analyses were performed using the 8.0 release version of SPSS for Windows®. (SPSS Inc, Chicago IL, USA).

Results

The "ghosting" routine elicited a marked physiological response in participants during the pre-supplementation condition (fatigue index 5.5 ± 1.6%, peak $[La^-]_B$ 8.0 ± 0.5 mM, and mean f_c 176 ± 2 beats × min^{-1} [89.2 ± 0.8% $f_c$max]). All experimental subjects improved mean time for all 10 sprints (i.e., mean set sprint time) by an average of 4.7 ± 0.3% (31.66 ± 0.56 vs. 30.16 ± 0.51 s for pre- and post-Cr, respectively, range = 3.3 to 6.6%). The control group exhibited less marked improvements in mean set sprint time of 1.5 ± 0.6% (31.51 ± 0.36 vs. 31.04 ± 0.34 s for pre- and post-placebo, respectively). The experimental group improved set mean sprint time by 3.2 ± 0.8% over and above the changes noted for the control group (P = 0.004; 95% CI = 1.4 to 5.1%). These changes are illustrated in Fig. **3**. Sets 2 to 10 were significantly quicker following Cr supplementation compared to the placebo condition (Figs. **4,5,6**). Heart rate and $[LA^-]_B$ were unaffected by Cr supplementation (P > 0.05; Table **2**).

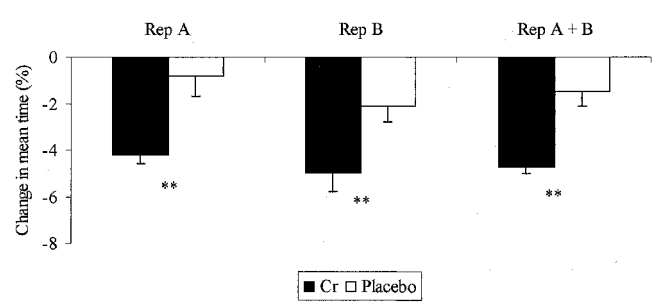

Fig. 3 Relative change in mean repetition and set time for experimental and control conditions (mean ± SEM). Note: **P < 0.01.

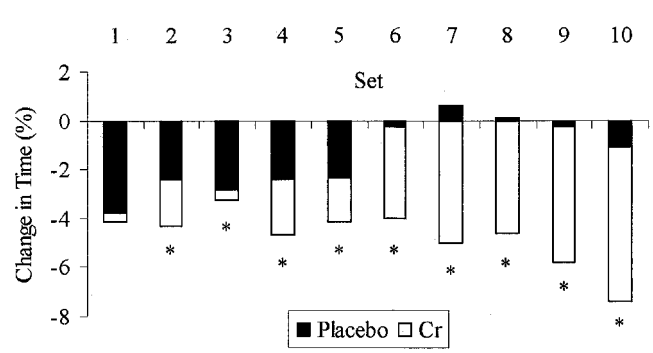

Fig. 4 Relative change in set time for experimental and control conditions. Note: *p < 0.05.

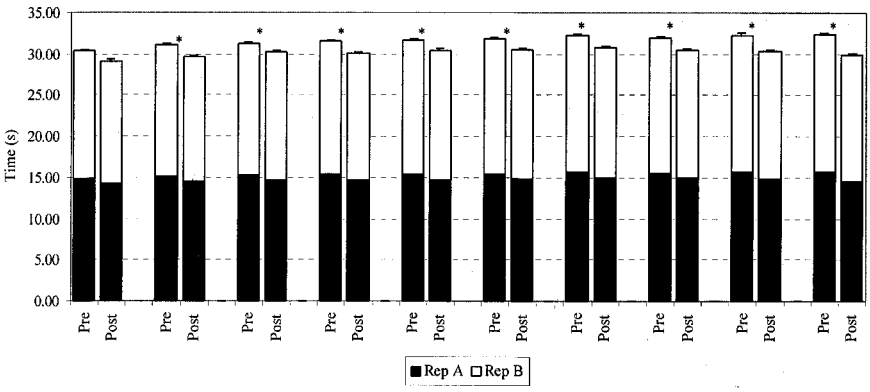

Fig. 5 Absolute change in repetition and set time for the experimental condition (mean ± SEM). Note: *P < 0.05.

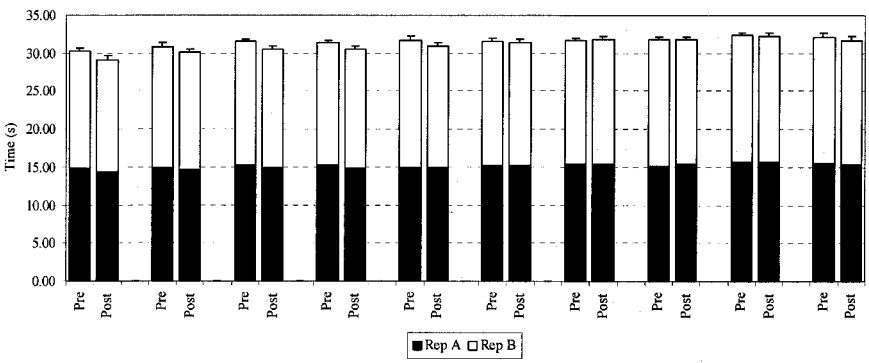

Fig. 6 Absolute change in repetition and set time for the control condition (mean ± SEM).

Table 2 Data for mean set blood lactate and heart rate (mean ± SEM)

	Cr		Placebo	
	Pre	Post	Pre	Post
Blood lactate (mM)	7.3 ± 0.6	6.7 ± 0.55	6.6 ± 0.4	6.8 ± 0.4
Heart rate (beats×min^{-1})	174 ± 2	173 ± 2	177 ± 2	176 ± 2
Heart rate (%max)	89 ± 1	88 ± 1	90 ± 1	89 ± 2

Both control and experimental groups were found to be asymptomatic throughout the period of intervention – none of the participants reported an increased incidence of cramping, gastrointestinal distress, nausea, dizziness, and/or dehydration following Cr supplementation. However, a significant 1.5 ± 1.3 % gain of body mass was observed in the Cr group (73.5 ± 10.2 vs. 74.5 ± 9.9 kg for pre- and post-Cr, respectively, P = 0.03). A non-significant correlation was found between the relative changes in body mass and mean sprint time following Cr supplementation (r = –0.16; P = 0.68).

Discussion

Main findings

Repetitive sprint

To the authors' knowledge, this is the first study to confirm the potentiating effect of Cr supplementation on high intensity, intermittent exercise performance in squash players. The results are in agreement with those from several placebo-controlled laboratory [5,12,14,29,42,50] and field [2,3,24,28,33,38] studies investigating the influence of Cr supplementation on repetitive sprint performance. However, the results are contrary to the findings of other studies that were unable to demonstrate an ergogenic effect of Cr supplementation on repetitive sprint performance in the laboratory [4,10,11,15] or field [6,37,43,44,47]. Possible explanations for these discrepancies may be related to individual variability in response to Cr supplementation, insufficient time to allow washout of Cr in crossover studies, a large inter-individual variance in exercise performance coupled with a small sample size, and/or use of exercise protocols with a greater emphasis on aerobic versus anaerobic metabolism.

Single sprint

Although on balance it appears that repetitive sprint performance can be improved following Cr supplementation, the question whether Cr administration improves performance in a single bout of exercise remains controversial. On closer inspection of the data, mean time to complete repetitions 1 and 2 was not significantly different following Cr supplementation compared to the placebo condition This finding is in agreement with previous studies that have shown non-significant improvements in single exercise bouts lasting up to 30 s following Cr supplementation [6,12,37,39,46,48]. In contrast, other studies have demonstrated a potentiating effect of Cr supplementation on single sprint performance of similar duration [3,5,8,14,23,24,42]. The explanation for the apparent conflict in research findings is unclear but may stem from variations in the duration of exercise used to evaluate performance.

Critique of methods

Reliability of test

As previously mentioned, a large inter-individual variance in exercise performance coupled with a small sample size may partly explain why several studies have failed to demonstrate an ergogenic effect with Cr supplementation. The small relative variability of the participant group over its distribution on mean set time following one familiarisation trial (CV = 1.5%) suggests that the "ghosting" routine used in the present study can be used to reliably detect small differences in exercise performance. Despite the dearth of data regarding test-retest reliability of repetitive sprint performance measures, the reliability coefficient for mean set time determined in the present study compares favourably with the results of previous investigations. Fitzsimons et al. [17] reported adequate reliability on test score for cycling (6 × 6 s efforts, departing every 30 s; CV = 2.5 – 4.0%) and running (6 × 40 m efforts, departing every 30 s; CV = 1.0 – 1.7%) tests of repeated sprint ability. More recently, Capriotti et al. [7] reported a mean CV of 2.8% for peak power achieved during a multi-sprint cycle test (10 × 7 s, departing every 30 s) after two familiarisation sessions.

An advantage of the present study over many previous field-based studies on the ergogenic effects of Cr supplementation is that the participant group was comprised of well-trained individuals. All participants were at least senior county level, and three individuals were GB national standard. Indeed, $\dot{V}O_2$max for the participant group studied (61.7 $ml \cdot kg^{-1} \cdot min^{-1}$) was higher than the values reported for "high level" Canadian players (56.0 $ml \cdot kg^{-1} \cdot min^{-1}$) [34] and top club South African males (59.5 $ml \cdot kg^{-1} \cdot min^{-1}$) [52], but was comparable to values reported for elite Asian (61.7 $ml \cdot kg^{-1} \cdot min^{-1}$) [9] and Irish (63.3 $ml \cdot kg^{-1} \cdot min^{-1}$) [49] males. The well-trained nature of the participant group might have enabled those individuals to pace themselves more reproducibly during the "ghosting" routine, perhaps because their perceptions of effort or fatigue that limit performance were less variable. Likewise, all participants were accustomed to performing "ghosting" routines during normal training, which would likely improve further the reliability of performance measures.

Specificity of test

The performance test used in the present study was chosen on the basis that: 1) time and motion analyses of squash games during actual competition have consistently revealed a 1:1 work to rest ratio [36], 2) for top level players a small but important 20% of rallies last more than 20 s with 8% lasting more than 30 s [36], 3) "shadow" or "ghosting" interval regimens, similar to the one used in the present study, are an effective anaerobic glycolytic training stimulus commonly used by squash players [44]; and 4) the routine elicits a marked physiological response similar to that encountered during competitive match play. Indeed, peak blood lactate recorded after the final repetition was 8.0 mM, which compares favourably with peak lactate values reported for actual match play in highly skilled individuals playing against an opponent of equal ability (8.0 mM) [34]. Furthermore, heart rate averaged 89% of maximum, which is comparable to the mean heart rate typically maintained throughout a match (80 to 90% $f_c$max) [36].

Functional relevance of test

Although this study identified a significant 3.2% effect in repetitive sprint performance above control conditions (and the 95% confidence interval for this outcome included an enhancement of almost twice this magnitude), we are unable to determine the precise influence this improvement might have on actual match performance. We speculate that improvements in actual match performance will be even more marked. For professional and "grade A" players 80% of rallies last less than 20 s and 49% last 10 s or less, and the average match (best of five games) may last from 30 to 90 min [36] up to a maximum of 2 h 45 min [44]. The cumulative effect of shorter rallies, which are more reliant on the ATP-PCR energy system, performed over a longer time period would be likely to challenge the immediate energy system more than in the present study. Future studies might consider investigating the effects of Cr supplementation on exercise performance by using simulated match play to mimic the physiological demands of high level squash, and utilise an outcome measure that has appropriate external validity, for example, shot accuracy.

Potential mechanisms

The precise mechanism by which Cr achieves its acute ergogenic effect is not yet clear. Research to date suggests that it may be related to increased availability of pre-exercise PCr, particularly in Type II muscle fibres [8]. In addition, Cr supplementation has been reported to accelerate post exercise PCr resynthesis [22]. Collectively, these mechanisms would be expected to maintain ATP turnover during exercise and increase muscle contractile capability. Support for this suggestion originates from maximal exercise studies demonstrating attenuated adenine nucleotide degradation (as measured by the accumulation of plasma ammonia and hypoxanthine) following Cr supplementation, despite the completion of more work [2,5,23]. More direct evidence stems from the finding that the reduction in muscle ATP during maximal isokinetic cycling exercise was attenuated by -30% following Cr supplementation, despite a higher work output [8]. However, more recently it was found that Cr supplementation did not facilitate muscle PCr resynthesis during intermittent isometric muscle contractions, despite raising skeletal muscle PCr concentrations and improving performance during rapid and dynamic intermittent muscle contractions [51]. Moreover, higher pre-exercise concentrations of PCr at rest compensated for significantly slower recovery rates of PCr after Cr supplementation [32]. Collectively, these studies oppose the notion of increased PCr resynthesis and support the idea of higher starting levels of PCr.

Based on findings of lowered post-exercise lactate concentrations some authors have suggested that the resynthesis of ATP during high-intensity exercise would rely less on anaerobic glycolysis following oral Cr supplementation [2,29]. This would presumably attenuate the decrease in intramuscular pH and enhance resistance to fatigue. Nevertheless, the non-significant change in exercise blood lactate concentration observed in the present study suggests that a reduced metabolic acidosis was not the principal mechanism for improvement in exercise performance following Cr supplementation. This finding is in agreement with previous research, which have shown unchanged post-exercise lactate concentrations following Cr

supplementation [5, 6, 8, 15, 22, 23, 37]. Interestingly, blood lactate measured 2 min post-exercise was significantly lower than the value obtained immediately after the final repetition (7.2 ± 0.5 vs. 8.0 ± 0.5 mM, respectively). Rapid clearance of lactate following high intensity exercise is an important component of squash fitness, particularly given the marked metabolic consequences of the game, and is presumably a function of lactate uptake by both active and inactive muscle fibres and other gluconeogenic tissues.

Adverse effects

Individuals in the present study did not experience an increased prevalence of cramping, gastrointestinal distress, nausea, dizziness, or dehydration throughout the duration of study compared to baseline values. Anecdotal reports of adverse side effects following Cr ingestion are largely unsupported by the scientific literature. To date, no peer-reviewed studies have reported an increased prevalence of cramping following Cr supplementation, and acute Cr supplementation ($20\,g \cdot d^{-1}$ for 5 d) does not appear to adversely affect renal function in healthy individuals [40]. However, participants in the present study did experience a significant 1.0 kg (1.4%) increase in body mass following Cr supplementation. This increase was of magnitude similar to that reported by other investigators (0.5 to 2.0 kg) [31] and is probably the result of increased water retention representing the need for the muscle to dilute the increased concentration of solute in the muscle to maintain osmotic gradients and hydration status [31]. Although an increase in body mass might be expected to hinder exercise performance in a weight bearing sport such as squash, the non-significant correlation between relative changes in body mass and exercise performance does not lend support to this contention. Data concerning the potential adverse effects of chronic Cr supplementation are limited, although a recent controlled study suggests that long-term Cr supplementation ($10\,g \cdot d^{-1}$ for 5 years and $30\,g \cdot d^{-1}$ for one year) in healthy adults poses no threat to normal physiological function [41].

In conclusion, these data support existing evidence that Cr supplementation improves high intensity, intermittent exercise performance. In addition, the present study provides new evidence that oral Cr supplementation improves exercise performance in competitive squash players.

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