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THE EFFECTS OF CREATINE SUPPLEMENTATION ON SINGLE AND INTERMITTENT ANAEROBIC EXERCISES AND BODY COMPOSITION DURING REDUCED TRAINING IN SOCCER PLAYERS

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Abstract

BACKGROUND: Several studies have examined the effects of creatine supplementation in adult athletes in season or pre-season preparation. However, few studies have examined the effects of creatine supplementation in adolescent soccer players during reduced training in an off-season. OBJECTIVE: The aim of the study was to examine the effects of short-term creatine monohydrate supplementation on the anaerobic performance and body composition in adolescent soccer players during reduced training in an off-season. METHODS: Using a double-blind experiment design, 16 soccer players (aged 18.0 ± 0.8 yr) were randomly assigned to 5 days of either 20 g . day^{-1} creatine monohydrate (Cr) or placebo supplementation. One day before and a day after the supplementation, participants completed squat and countermovement jumps (SJ, CMJ), 10-m running sprint, 6-s single cycling sprint (CST), an intermittent anaerobic test on a bicycle ergometer (10 x 6s, IAnTBE) and measurement of body composition. RESULTS: Cr supplementation had no significant effect ($p > .05$) on any performance test. However, effect size values indicated medium or small clinical significance in SJ ($d = 0.59$), CST (6-s power, $d = 0.50$; peak power, $d = 0.48$) and IAnTBE (best peak power, $d = 0.44$; post-exercise blood lactate concentration, $d = - 0.59$; fatigue index, $d = - 0.28$). Relative to the placebo, Cr supplementation resulted in a significant increase in body weight (BW) ($p = .015$). CONCLUSIONS: The results of the study suggest that short-term Cr supplementation administered to adolescent soccer players during their off-season significantly increase body weight and could have small/medium clinical significance effect on improve lower-body maximal anaerobic power output and power output recovery during maximal intermittent exercise. The study also confirms that Cr supplementation is safe and without side effects for adolescent athletes.

Keywords

muscle power output; bicycle ergometer; fatigue index; sprint; vertical jump

1 INTRODUCTION

The acute (short-term, loading) Cr supplementation, usually ingested in the form of creatine monohydrate in a dose of 20-25 g.d^{-1}/0.3 g.kg^{-1} for 5-7 days, was shown to increase total intramuscular creatine (Cr) and phosphocreatine (PCr) (Greenhaff et al., 1994, Harris et al., 1992; Solis et al., 2017). Increased muscular PCr may lead to enhancement in maximal dynamic and isometric muscle force/strength, anaerobic power and intermittent anaerobic performance (Bemben & Lamont, 2005; Izquerdo et al., 2002; Urbanski et al., 1999). Soccer has been defined as an intermittent sport as a player's performance involves repeated explosive actions of the lower limbs such as sprinting, turning, jumping, tackling, kicking and forceful contractions to maintain balance and control the ball executed over a prolonged period (Stølen et al., 2005). Thus, soccer players might benefit from two possible ways in which CrS is thought to improve physical performance. First, increased intramuscular PCr presents an increased energy pool, supports rephosphorylation of ADP, and enhances high energy phosphate diffusion between the mitochondria and myosin heads leading to better engagement in cross bridge cycling and tension maintenance (Bemben & Lamont, 2005; Greenhaff et al., 1994). Secondly, Cr supplementation can act to increase the rate of PCr resynthesis after intensive exercise and, as a consequence,

ameliorate metabolic recovery between successive bouts of very high intensity exercise (Yquel et al., 2002). In soccer players, both mentioned CrS benefits were confirmed by several studies (e.g. Claudino et al., 2014; Cox et al., 2002; Mujika et al., 2000; Ramírez-Campillo et al., 2016; Yaňez-Siva et al., 2017), but not all (Williams et al., 2014).

The ambiguous effects of Cr supplementation on both single and repeated bouts of high intensity exercise might result not only from the biochemical and functional properties of muscle fibres of consumers (responders vs. non-responders) (Greenhaff et al., 1994; Syrotuik & Bell, 2004) and a Cr supplementation strategy (acute vs. maintaining) (Cooper et al., 2012), but also from different training regimes given by frequency and intensity of physical/muscle loading undergone during the Cr ingestion period. Typically, ergogenic effects of Cr supplementation have been investigated when players simultaneously underwent regular intensive training during a competitive season (Gouttebarge et al., 2012; Ramírez-Campillo et al., 2016) or pre-season or an intensive preparation period that involved strength/power training and conditioning, specific soccer exercises and game-like training (Claudino et al., 2014; Cox et al., 2002; Larson-Meyer et al., 2000). However, there is very limited knowledge on any possible effect of acute Cr supplementation during a period of significant reduction of training such as in the post-season (transient season) of soccer teams when only two studies have yet been published. In the first study (Yaňez-Siva et al., 2017) elite adolescent soccer players who had 5 training sessions plus one match a week during their competitive season, ingested Cr (0.03 $g.kg^{-1}.d^{-1}$) for 14 days during in the middle stage of the competitive season while physical loading was reduced to two training sessions a week. In spite of this reduction, Cr ingestion resulted in a significant increase in peak power output and total work in the 30-s Wingate cycling test while placebo did not.

In the second study (Mujika et al., 2000) highly trained adult soccer players underwent 6-day Cr supplementation (20$g.d^{-1}$) that began three days after the last match of the competitive season. During the investigation the training load was reduced but no information is provided on the extent of the reduction. As compared to the placebo, the Cr-induced improvement was reported for the 5-m times in two sprints of the repeated 6x 15 m sprint test and not for vertical jump and performance in an intermittent endurance test. As the Cr supplemention took place immediately after the last match of the competitive season in this study, the improvement of RSA might be rather attributed to a tapering effect. In addition, the first above-mentioned study (Yaňez-Siva et al., 2017) reported an effect on anaerobic power and capacity of legs but information about how much time of reduced training preceded the Cr investigation is missing. Therefore the purpose of the study was to examine effects of acute Cr supplementation in the advanced stage of the post-season featured with reduced soccer training. According to training periodization in competitive sport (Bompa & Haff, 2009), the purpose of a post-season following the end of the competitive season is physical and mental regeneration but minimalizing decrease in the physical performance and sport-specific skills of players, while significantly reducing volume and/or training intensity. The study was focused on examining whether Cr supplementation applied in the advanced stage of the reduced post-season training might support maintaince of muscle strength and power in soccer players.

In addition, the efficacy of Cr supplementation on physical performance might be moderated by its effect on body composition, specifically, by the increase in body weight that is most likely contributed from increased total body water including intramuscular water, and/or an increase in body lean mass due to possible myofibrillar protein synthesis (Branch, 2003; Gutiérrez-Sancho et al., 2006). Therefore, the current study investigated the effects of CrS on the physical performance of soccer players with regard to possible changes in body composition.

2 MATERIALS AND METHODS

Participants

Sixteen male soccer players (age 18.0 ± 0.8 yr, range 17–19) from one team competing in a 3rd U19 league (regional league) were recruited as participants for the experiment. Over the last year, the players usually

underwent 3–4 training sessions a week, with a mean duration of 90 min, plus one official match a week. The total time of their regular soccer training was 9.1 ± 2.3 yr. The exclusion criteria for participation on the study was assessed verbally and included: i) the position of the goalkeeper, ii) chronic and acute physical and/or mental problems and iii) long-term or current ingestion of any medication. None of the participants was a vegetarian or ate unusually large quantities of meat.

Participants and their legal guardians (if <18.0 yr) received information about the study and the possible risks and discomforts associated with the experiment. Then, the legal guardians and/or players gave their written informed consent to participation. All of the experimental procedures done met the Code of Ethics of the World Medical Association (the Helsinki Declaration, 2000). The study was approved by the the University's institutional ethical committee, and the technical staff and the medical supervisor of the club.

Experimental design

The study was designed as a double-blind randomised placebo-controlled experiment, involving the creatine (Cr) group (N = 8) and the placebo (Pl) group, (N = 8) (Table 1). An a priori power analysis showed that 12 participants would be sufficient to identify a significant effect of the two independent variables (time: pre, post, group: Cr, Pl) with a within-subject design with a power (1 - β) of .80, effect size f of .50 and an α of .05 (Faul, Erdfelder, Lang, & Buchner, 2007).

One day before and one day after the 5-d supplementation, participants of both groups underwent the pre- and post-test session, respectively.

Training protocol

The experiment was carried out during the fourth week of the eight-week post-season (at the beginning of December). During the four weeks, participants underwent "maintenance" training that involved only two training sessions a week (75 min per session). Each training session involved warm-ups and individual and group soccer skill drills (20-25 min), which were followed by games of small sides with different numbers of players, sizes of fields, goals and rules, focused on various aspects of defensive and offensive phases of a game (30-45 min) and finished with 10 min of cooling down and regeneration exercises. No exercises primarily focused on stimulation of muscle strength and power, anaerobic or aerobic conditioning were included in the post-season training. Thus, the total time of training load of a post-season course was reduced from 360-450 min in the competitive season to 150 min a week in the post-season.

Supplementation protocol

Participants were administered 20 small plastic bags, identical in appearance, size, texture, taste and colour, with each containing either 5 g of creatine monohydrate plus 15 g of maltodextrin (Myprotein, Northwich, UK) or 20 g of maltodextrin. They were instructed to mix the contents of a bag in 250 ml of lukewarm or warm water and drink at regular intervals four times per day (intervals of 4 hours) for 5 d, the best with food. This instruction to consume the supplementation with food was given because this ingestion increases body´s Cr retention (Steenge et al., 2000). They were also asked to complete a written record of the time of supplementation each day. If they forgot to take a dose, participants were recommended to take it as early as possible after remembering or being reminded (see below) and then to modify the 3–4 hour interval supplementation schedule accordingly. Participants were encouraged to preserve their nutrition and physical activity habits that they usually maintain and not to combine the test supplement with other supplements.

Participants were also asked to report any adverse effects of supplementation such as changes in appetite, thirst, nausea, diarrhoea, frequent headaches, dizziness, muscle aches and cramping, decreased sensitivity of the neck, back or limbs, shivering, irritability and aggression. In addition, participants were contacted by one researcher by mobile phone once a day to check their health status, compliance with supplementation and regular

ingestion of the doses. The participants were also asked not to combine the test supplement with other supplements.

Pre- and post-tests

The pre- and post-test session involved the tests in the following order: i) basic anthropometric and body composition measurements, ii) a vertical squat jump and countermovement jump to assess the explosive strength of lower extremities, iii) a 10-m running sprint test to assess running sprint ability in the first acceleration phase, iv) an intermittent anaerobic test on a bicycle ergometer (IAnTBE) to assess repeated sprint ability. To perform all performance tests, participants wore shorts, T-shirts and indoor soccer shoes. All the tests were conducted under the same conditions such as time of day and place.

Anthropometric and body composition measurements

Body height was measured using the Tanita Leicester Height Measure device (Invicta Plastics Ltd, Leicester, England) with an accuracy of 0.1 cm. Body weight (BW) and body composition variables were assessed using a tetrapolar multi-frequency bioimpedance device InBody 230 (InBody Co., Ltd., Soul, South Korea).

Vertical jump tests

After a 10-min warm-up that consisted of static and dynamic stretching and low-intensity running, participants performed vertical squat jumps (SJ) and countermovement jumps (CMJ), both with arm fixation while keeping their hands on their iliac crests. SJs were executed from a position of 90° of knee flexion, stopping 1–2 s, and then jumping as high as possible, without knee and/or trunk countermovement. CMJs were executed from a standing position, legs moderately apart. For each jump test, participants were provided with one demonstration, followed by one practice trial and three test trials, separated by 30-s recovery. An optoelectronic instrument Optojump Next, version 1.3.20.0 (Microgate, Bolzano, Italy) was used to measure the jump height based on flight time. Participants jumped between the light emitting and two parallel receiving bars of this device placed 1.5 m apart. The highest jump best of the three trials was always used as the dependent variable.

Single running sprint test

3 minutes after performing of the SJ and CMJ tests, each participant performed one practice trial and three test trials of the 10-m sprint test, with 90-s recovery after each sprint. Participants started from a standing position, with the toe of the preferred foot forward and 30 cm behind the position of a start photocell. Sprint times were measured with infrared electronic cells (Timing Brower Systems, Draper, USA) placed at the level of the participant's shoulder minus 10 cm. The shortest time achieved of the three trials was used as a dependent variable. The sprint and jump tests were performed in a sports hall on an artificial surface.

Single cycling sprint test (CST)

20 minutes after completing the running sprint test, each participant underwent the CST consisting two single 6-s cycling sprints on a bicycle ergometer, the Monark 894 Peak Bike (Vansbro, Sweden) in a lab to assess maximal anaerobic power. Prior to the test, a participant performed a 5-min warm-up while pedalling at a moderate rate against a resistance of 1.9% BW. 2 minutes after the warm-up, the participant executed two 6-s familiarisation cycling sprints of non-maximal intensity against a resistance of 1.9% BW with 2-min recovery between the sprints.

2 minutes after the familiarisation, a participant performed two single 6-s maximal sprints separated by 3 min passive recovery. Pedalling was executed in the sitting position, against a resistance of 7.5% BW by a mechanical belt brake. The weight brake resistance dropped the moment a pedalling frequency of 120 rpm was attained. The seat height was adjusted for each participant. The standard start position of the pedals before each sprint was kept with the dominant leg in the upper position. During the all-out test participants were encouraged to perform at their maximum. The higher 6-s power of two trials was used for the analysis.

Intermittent anaerobic test on bicycle ergometer (IAnTBE)

5 min after the cycling sprints, participants underwent the IAnTBE consisting of ten 6-s cycling sprints against a resistance of 7.5% BW. The rest interval between the two consecutive sprints was 30 s. Adjustment of the seat height, sitting position, pedalling frequency for dropping the weight brake resistance, the start position of the pedals before each work interval and encouragement of a participant were the same as for the single cycling sprint test. To assess post-exercise blood lactate concentration, a drop of blood was taken from the fingertip 3 minutes after finishing the IAnTBE (BLa_{3min}; $mmol \cdot L^{-1}$) and analysed by LactateScout+ analyzer (EFK Diagnostics, Cardiff, Wales).

The mechanical power measures assessed are presented in Table 2. The fatigue index of 6-s power (FI_{P6s}) was calculated by using the formula (Glaister et al., 2008):

$$FI_{P6s}\,(\%) = 100 - [(P_{mean} / P_{6s\,max} \times 100]$$

where P_{mean} ($W \cdot kg^{-1}$) is the mean power across the whole test, and $P_{6s\,max}$ ($W \cdot kg^{-1}$) is the highest 6-s power. Similarly, the fatigue index of peak power (FI_{Ppeak}), i.e. highest power per revolution in each work interval, was calculated by using the same the formula ([19]): $FI_{Ppeak}\,(\%) = 100 - [(P_{peak\,mean} - P_{peak\,max}) \times 100]$, where $P_{peak\,mean}$ ($W \cdot kg^{-1}$) is the mean peak power across all work intervals, and $P_{peak\,max}$ ($W \cdot kg^{-1}$) is the highest peak power in the test.

Data analysis

All the values are reported as the means ± standard deviations. To examine the effects of Cr supplementation on dependent variables, a 2 (Cr vs. placebo) x 2 (pre vs. post) mixed-design analysis of variance with repeated measures (RM ANOVA) on the second factor was conducted. Bonferonni corrections were employed for post-hoc comparisons to reduce the probability of type I error. To assess the clinical significance, effect sizes (ES) were calculated according to the equation:

(mean pre-post difference of the Cr group – mean pre-post difference in the placebo)/ pooled SD_{post}) and defined as trivial (≤ 0.2), small (< 0.5), medium (< 0.8) and large (≥ 0.8) (Cohen, 1992). The magnitude of the difference for each variable was expressed by 95% confidence limits.

3 RESULTS

The analysis of variance showed significant group x time interaction for body weight (BW), F (1.14) = 6.092, p = .027, with a mean increase of BW by 0.8 ± 0.8 kg in the Cr group while the placebo led to a mean decrease of 0.1 ± 0.6 kg during the experiment (Table I). The time and group, as well as their interaction were not significant for other body composition measures but in some of them a small clinical effect was recorded (Table 1).

The effect of both the time and the group, and their interaction were not significant for performance in vertical jumps (SQ, CMJ), 10-m running sprint, CST (Table II) and IAnTBE (table III). However, the Cr supplementation led to the medium clinical significance in height of squat jump (+ 2.44 cm, d = 0.59), 6-s power in CST (+0.65 ± 0.79 $W.kg^{-1}$ BW, d = 0.50) and decrease of post-exercise BLa in IAnTBE (- 3.5 $mmol.L^{-1}$, d = - 0.59). For other measures a small or trivial clinical effect was observed (Table 2, Table 3).

Table 1. Anthropometric and body composition measures in the creatine group and the placebo group in the pre- and post-test (mean ± SD).

	Baseline mean ± SD	Mean Diff ± SD	95%CI	d (ES)	p (interaction)
Weight (kg)					
Creatine	71.3 ± 8.5	0.77 ± 0.75	0.25; 1.19	0.14	0.027
Placebo	73.9 ± 5.4	-0.14 ± 0.62	-0.57; 0.29		
BMI					
Creatine	22.1 ± 1.8	0.26 ± 0.24	0.09; 0.43	0.15	0.024
Placebo	23.4 ± 2.6	-0.05 ± 2.27	-0.20; 0.10		
FFM (kg)					
Creatine	62.7 ± 7.0	0.74 ± 1.55	-0.33; 1.81	0.26	0.144
Placebo	65.5 ± 4.3	-0.68 ± 1.85	-1.96; 0.60		
PBF (%)					
Creatine	11.9 ± 3.8	-0.08 ± 1.64	-0.22; 1.06	-0.19	0.438
Placebo	11.3 ± 1.7	0.70 ± 1.98	-0.67; 2.07		
TBM (kg)					
Creatine	35.7 ± 4.1	0.51 ± 0.97	-0.16; 1.18	0.27	0.142
Placebo	37.4 ± 2.8	-0.39 ± 1.18	-1.21; 0.43		
TBW (kg)					
Creatine	45.9 ± 5.0	0.55 ± 1.11	-0.22; 1.32	0.28	0.118
Placebo	48.0 ± 3.1	-0.56 ± 1.38	-1.52; 0.40		
IntW (kg)					
Creatine	28.9 ± 3.2	0.40 ± 0.77	-0.13; 0.93	0.46	0.177
Placebo	29.7 ± 1.1	-0.83 ± 2.15	-2.32; 0.66		
ExtW (kg)					
Creatine	17.0 ± 1.9	0.15 ± 0.36	-0.10; 0.40	0.09	0.489
Placebo	17.8 ± 0.9	0.00 ± 0.43	-0.30; 0.30		

BMI – body mass index; FFM – fat free mass; TBF – total body fat; PBF – percentage of body fat; TBM – total body muscles; PBM – percentage of body muscles; TBW – total body water; PBW – percentage of body water; IntW, ExtW – percentage of intracellular and extracellular water, respectively; BCM – body cell mass; PRE – pre-test; POST – post-test; p – p-value (t-test); d – Cohen´s d effect size; * p<0.05.

Table 2. Performance in the 10-m running sprint, jump tests, and mechanical power measures at single 6-s cycling sprint in the creatine group and the placebo group in the pre- and post-test (mean ± SD).

	Baseline mean ± SD	Mean Diff ± SD	95%CI	d (ES)	p (interaction)
Squat jump (cm)					
Creatine	33.5 ± 2.6	2.44 ± 3.69	-0.12; 5.00	0.59	0.182
Placebo	38.1 ± 5.0	-0.05 ± 2.88	-2.05; 1.95		
CM jump (cm)					
Creatine	37.7 ± 4.2	0.28 ± 3.49	-0.14; 0.70	0.21	0.463
Placebo	41.6 ± 7.0	-0.84 ± -0.84	-1.42; -0.26		
Sprint 10 m (s)					
Creatine	1.88 ± 0.05	0.01 ± 0.04	-0.02; 0.04	0.00	0.890
Placebo	1.86 ± 0.05	0.01 ± 0.06	-0.03; 0.05		
P_{6s} ($W \cdot kg^{-1}$)					
Creatine	12.0 ± 0.6	0.65 ± 0.79	0.10; 1.20	0.50	0.244
Placebo	12.3 ± 1.2	0.24 ± 0.41	-0.04; 0.52		
P_{6s} ($W \cdot FFM^{-1}$)					
Creatine	13.7 ± 1.0	0.73 ± 0.83	0.15; 1.31	0.43	0.324
Placebo	13.9 ± 1.2	0.33 ± 0.59	-0.08; 0.74		
P_{peak} ($W \cdot kg^{-1}$)					
Creatine	13.8 ± 1.1	0.82 ± 0.83	-0.24; 1.40	0.48	0.131
Placebo	14.6 ± 1.5	0.23 ± 0.51	-0.12; 0.58		
P_{peak} ($W \cdot FFM^{-1}$)					
Creatine	15.7 ± 1.6	0.92 ± 0.76	0.39; 1.47	0.42	0.14
Placebo	16.4 ± 1.6	0.32 ± 0.66	-0.14; 0.78		

SJ – squat jump; CMJ – countermovement jump; P_{6s} – the average mechanical power at the 6-s cycling sprint; P_{peak} – the peak power per one revolution at 6-s cycling sprint; PRE – pre-test; POST – post-test; p – p-value (t-test); d – Cohen´s d effect size; * p<0.05.

Participants did not report medical problems, symptoms or their adverse effects during the Cr supplementation period. Also, no muscular injury or cramping was observed during training and post-test sessions.

Table 3. Mechanical power measures and postexercise blood lactate concentration in the IAnTBE in the creatine group and the placebo group in the pre- and post-test (mean ± SD).

	Baseline mean ± SD	Mean Diff ± SD	95%CI	d (ES)	p (interaction)
$P_{peak\ max}$ ($W \cdot kg^{-1}$)					
Creatine	14.0 ± 0.9	0.35 ± 0.60	0.07; 0.77	0.44	0.198
Placebo	14.4 ± 1.6	-0.24 ± 0.98	-0.92; 0.44		
$P_{peak\ max}$ ($W \cdot FFM^{-1}$)					
Creatine	15.9 ± 1.4	0.38 ± 0.47	0.05; 0.71	0.29	0.45
Placebo	16.2 ± 1.7	-0.02 ± 1.27	-0.90; 0.86		
$P_{6s\ max}$ ($W \cdot kg^{-1}$)					
Creatine	12.1 ± 0.6	0.11 ± 0.37	-0.15; 0.37	-0.01	0.961
Placebo	12.3 ± 1.2	0.13 ± 0.63	-0.31; 0.57		
$P_{6s\ max}$ ($W \cdot FFM^{-1}$)					
Creatine	14.1 ± 1.1	-0.19 ± 0.81	-0.75; 0.37	-0.40	0.37
Placebo	13.6 ± 1.2	0.22 ± 0.84	-0.36; 0.80		
P_{mean} ($W \cdot kg^{-1}$)					
Creatine	9.6 ± 1.0	0.34 ± 0.48	0.01; 0.67	0.17	0.458
Placebo	10.0 ± 0.6	0.18 ± 0.25	0.01; 0.35		
P_{mean} ($W \cdot FFM^{-1}$)					
Creatine	11.0 ± 1.2	0.37 ± 0.58	-0.03; 0.77	0.11	0.69
Placebo	11.2 ± 0.7	0.25 ± 0.48	-0.08; 0.58		
FI_{P6S} (%)					
Creatine	30.6 ± 16.7	-0.61 ± 5.15	-4.18; 2.96	-0.02	0.945
Placebo	26.6 ± 9.2	-0.39 ± 6.60	-4.96; 4.18		
FI_{Ppeak} (%)					
Creatine	20.3 ± 8.9	-1.96 ± 3.96	-4.70; 0.78	-0.28	0.327
Placebo	17.4 ± 6.8	0.12 ± 3.71	-2.45; 2.69		
BLa ($mmol \cdot l^{-1}$)					
Creatine	19.6 ± 5.6	-3.46 ± 3.92	-6.18; -1.14	-0.59	0.373
Placebo	17.6 ± 4.2	-1.32 ± 4.75	-4.61; 1.97		

$P_{6s\ max}$ – the highest mean 6-s mechanical power; $P_{peak\ max}$ – the highest peak power per one revolution, $P_{peak\ mean}$ – the mean of the peak powers per one revolution; P_{mean} – the mean power in the all test; BLa – post-exercise blood lactate concentration; PRE – pre-test; POST – post-test; p – p-value (t-test); d – Cohen´s d effect size; p<0.05.

4 DISCUSSION

Our results showed that 5-day supplementation of 20g/d of creatine monohydrate mixed with maltodextrin in the ratio 1:3, divided into four equal doses and used in the middle of the post-season that was featured significantly reduced training of soccer players, led to a significant increase in body weight (BW), in contrast to the placebo. The mean change of BW in the Cr group 0.8 ± 0.8 kg was similar to that reported in other studies with soccer players who consumed Cr monohydrate over 5-6 days (Gouttebarge et al., 2012; Mujika et al., 2000). There is a suggestion that the early change in BW following Cr supplementation is mainly attributed to increased water retention in the intracellular compartments within muscle cells, probably due to the increased osmotic load caused by the increased intracellular Cr concentration (Bemben & Lamont; 2005; Deminice et al., 2016) The body water retention was also suggested in the current study. Although no significant change, the effect of the Cr supplementation on the change in intracellular water was close to medium effect (d = .46) with an obvious difference of mean individual change in the the Cr group as compared to the placebo group (table 1).

Our results also suggested a certain tendency towards increase in fat free mass (FFM) and total body muscles (TBM) following Cr ingestion as the positive small effect sizes were found (*d* = 0.26 and 0.27). These effects might partly contribute to the significant enhancement of BW. However, the increase in muscle size may be primarily due to intracellular water retention (Bemben & Lamont; 2005; Mesa et al., 2002). In addition, an increase in the cross-sectional area of muscle fibers as well as myogenic regulatory factors is achieved when a concurrent longer resistance training intervention is applied (Branch, 2003; Cribb et al., 2007; Deldicque et al., 2008). As participants in the current study underwent the reduced training regime throughout the post-season, based on soccer-skill and game practice, without muscle strength/power training, the increase in BW was most likely associated with increase in intracellular water.

Performance in SJ and CMJ are recognised as valid measures of explosive strength of lower limbs, mainly contributed from the knee and hip extensors' moments (Ford et al., 2009). Furthermore, sprint acceleration has been reported to be strongly determined by lower limb strength, specifically by hip extensor and knee flexor muscle contractions, including eccentric hamstring capability (Morin et al., 2015; Schache et al., 2015). The benefit of Cr supplementation for the enhancement of explosive muscle strength of lower limbs seemed not be proved in movement actions (jumping, accelerated sprinting) that are specific for soccer.

In contrast to performance in both jumps and the accelerated sprinting, three measures of maximal anaerobic power assessed with the CST and one measure with repeated cycle sprints (IAnTBE) were enhanced following Cr supplementation (in 7 and 6 respectively of 8 participants). These measures of maximal mechanical power (see Methods and Results) are assumed to be the expression of the maximal rate of anaerobic ATP synthesis (Driss & Vandewalle, 2013). Specifically in the current study, maximal anaerobic power in the CST was indicated by the mean 6-s power output and the peak power determined by the highest power output per one crank revolution (both measures related to BW and FFM). Participants usually achieved peak power between 3-5 s during 6-s single cycling. It was proved that ATP resynthesis during a single all-out exercise lasting ≤ 5-6 s is mainly provided from the breakdown of PCr (Bogdanis et al., 1998). Therefore, the results of the current study suggest that the 5-day Cr supplementation applied in soccer players might induce maintenance of ATP availability for repeated contractions of leg muscles during 6-s maximal intensity exercise, probably due to an increase in the PCr energy pool that helps to resynthesize ATP via hydrolysis of PCr (Ydfors et al., 2016).

The above-mentioned findings of the ergogenic effect of Cr supplementation for maximal anaerobic power might not influence jump performance and time of 10-m sprints when a vertical jump represents a single (one-off) muscle action of lower limbs and the duration of 10-m sprinting was 1.89 ± 0.05s. It is possible that jumping and very short sprinting can be more limited by inter- and intra-neuromuscular coordination including motor

unit recruitment rather than changes in the high-energy phosphate metabolism. This suggestion is supported by the meta-analysis by Branch (2003) that revealed the lower effect size for field exercise including running and jumping compared to laboratory-based isometric, isokinetic and isotonic exercises performed against very high resistance.

No significant effect of Cr supplementation on vertical jumps and the acceleration phase of sprinting might also be associated with the increase in BW. Body water retention induced from Cr supplementation may concern other body parts, besides lower limbs. BW is the key factor of anaerobic power output when assessed by resistance cycling (Driss & Vandewalle, 2013) while jumping and running are bearing activities. A vertical jump depends on vertical force generated by the legs to overcome gravity that directly relates to BW (Aragón-Vargas & Gross, 1997). Indeed, a change in body composition but not in BW was reported to be an important determinant of enhancement in performance of vertical jump (Gonzáles-Ravé et al., 2011) and sprint running (Barbieri et al., 2017).

Recent research has provided somewhat controversial findings on the ergogenic value of Cr supplementation for the ability to maintain muscle power output and running performance during maximal or very high intensity intermittent exercises (see Introduction). Enhancement of mean mechanical power in the IAnTBE was found in both Cr and placebo conditions (Figure 1). This finding might show more on the familiarisation or learning effect. The participants did undergo short familiarization (one week before the experiment) consisting of three sprints, but not this entire intermittent cycle test.

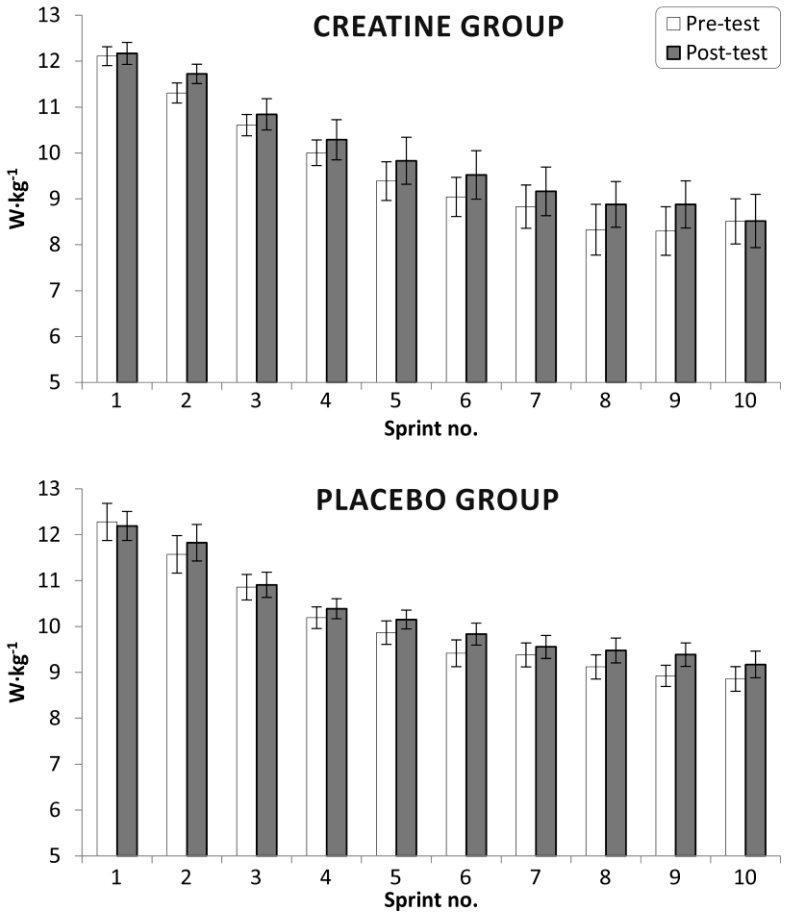

Figure 1. The mean 6-s mechanical power in consequent cycle sprints in the IAnTBE in the creatine group and placebo group.

However relative to the placebo condition, Cr ingestion led to an increase in mean peak power ($P_{peak\ mean}$; kg BW) by 4.4% during the IAnTBE (Figure 2). Furthemore, it is worth mentioning the relatively large, but not significant, decrease of FI_{6s} (by 9.7%) in comparison to increase in the placebo group (by 0.8%). These results could suggest increased PCr resynthesis during 30-s rest intervals. A strong relationship between PCr resynthesis and the recovery of power output during repeated very high intensity short duration bouts of exercise was reported (Bogdanis et al., 1996; Yquel et al., 2002). Higher PCr resynthesis and/or higher Cr availability is supported by the larger significant decrease of the post-exercise BLa (by 16.6%) after the IAnTBE following Cr supplementation in the current study. It is known that PCr decreases stimulation of non-oxidative glycolysis, and Cr buffers pH changes caused by increased intramuscular acidosis by utilising the hydrogen ions during the Cr kinase reaction (Spriet, 1992). Following 6-day Cr supplementation applied within the training program for the Olympic games, significantly lower BLa was observed in elite female soccer players after first and second block of 11minutes of the soccer-match simulating exercise (Cox et al., 2002).

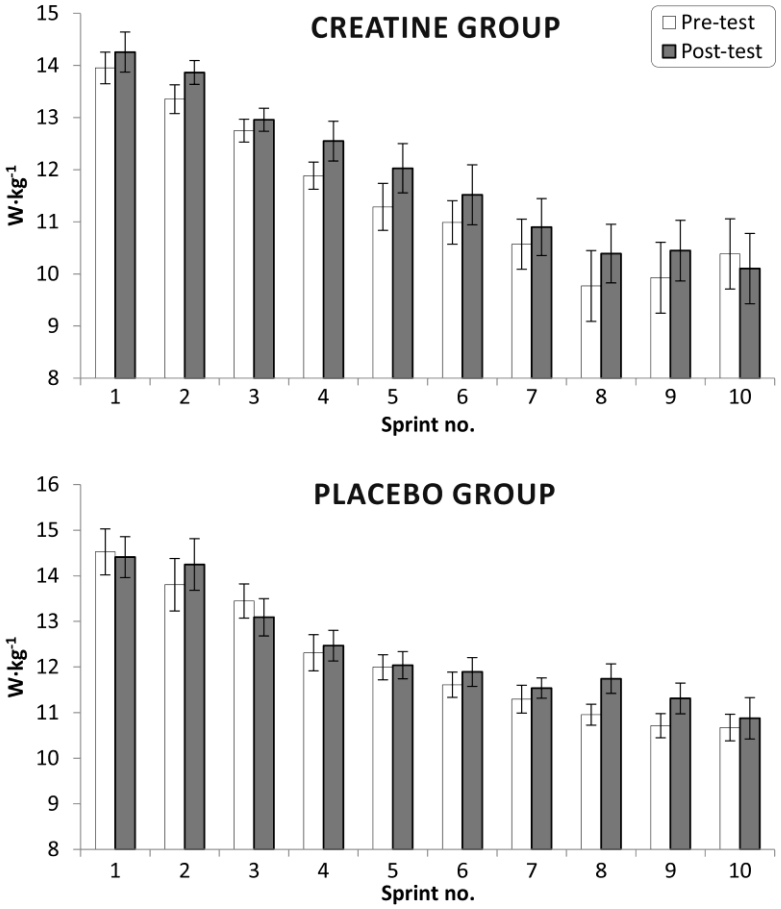

Figure 2. The mechanical peak power in consequent cycle sprints in the IAnTBE in the creatine group and placebo group.

A potential limit of the study is the smaller sample size. To better understand the effects of Cr supplementation, these effects should be investigated with respect to the physiological profile of participants. The effect of Cr supplementation may be affected by initial levels

of Cr and PCr, the relative proportion of type II skeletal muscle fibres, preload muscle fibre CSA (Rawson & Persky, 2007) and coincidental ingestion of protein and/or carbohydrate (Steenge et al., 2000). However in the current study, 6 or 7 of the 8 participants were responders to Cr supplementation with an increase in the particular measures of maximal anaerobic power. This extent of inter-individual muscle strength/performance response to Cr supplementation corresponds to reported estimations on 20-30% of non-responders (Greenhaff et al., 1994; Rawson a Persky, 2007).

5 CONCLUSIONS

In summary, the study shows that 5-day Cr supplementation with a dosage of 20 g of creatine monohydrate per day applied in young soccer players during their off-season can improves body weight, lower-body maximal anaerobic performance and recovery during maximal intermittent exercise. The study also confirms that short-term Cr supplementation is safe and without side effects for adolescent athletes. From a practical perspective, short-term Cr ingestion might be useful in the event of reduced training due to an injury, fatigue and other reasons for training restrictions for players. The study supports the current hypothesis that Cr supplementation is beneficial for enhancement in lower limb performance for exercises with a duration of less than 3 minutes, independent on population characteristics and training protocol

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