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EFFECTS OF THREE, FIVE AND SEVEN DAYS OF CREATINE LOADING ON MUSCLE VOLUME AND FUNCTIONAL PERFORMANCE

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Abstract The purpose of this study was to compare the effects of 3, 5, and 7 days of creatine loading coupled with resistance training on skeletal muscle volume and functional performance. Twenty active males were randomly assigned in a double-blind fashion to either the creatine group (Cr) (n=10) or the placebo group (Pl) (n=10). The Cr group consumed 20g of creatine per day (4 doses of 5g per day for 7 days), whereas the Pl group was given dextrose. The subjects performed resistance training at days 3, 5, and 7; and were tested also at days 4, 6, and 8. Significant increases in strength and standing long jump were observed after 3, 5, and 7 days of Cr ingestion ($p < 0.05$). There were significant improvements at 5 days in contrast to 3 days in body weight, 45-m sprint, standing long jump, 1RM back squat and arm curl ($p < 0.05$). Seven days of Cr loading made significantly greater improvements than 3 and 5 days in 4 × 9-m shuttle run and the arm cross-sectional area ($p < 0.05$). We conclude that more than 5 days of creatine regime are sufficient for improving muscle cross-sectional area, body weight, power and agility, whereas 3 days are sufficient for enhancing muscular strength.

Key words: Creatine monohydrate, performance, resistance training

INTRODUCTION

Creatine (Cr) is a popular dietary supplement that is used by athletes to increase muscle mass and strength and especially to improve sports performance [18, 24]. Cr is an organic compound synthesized mainly in the liver and kidneys from the amino acids glycine, arginine and methionine [32]. Cr plays an important role in rapid energy provision during muscle contraction involving the transfer of N-phosphoryl group from phosphorylcreatine to ADP to regenerate ATP through a reversible reaction catalyzed by phosphorylcreatine kinase (PCK) [32]. Phosphocreatine (PCr) plays a key role in energy provision to muscle cells. Dietary supplementation of Cr has been shown to increase muscle levels of both Cr and PCr by 20–50% [1, 12, 33].

Feeding 20-30 g Cr per day for several days is a common procedure that can indeed induce an increase in human skeletal muscle total creatine and phosphorylcreatine [20]. An increase in total muscle Cr can exert an ergogenic effect in high intensity exercise [18]; this effect can be explained by the increase of the rate of resynthesis of ATP during exercise and of PCr during recovery, delaying the appearance of fatigue. Because Cr supplementation increases the concentration of muscle PCr in many subjects, it is postulated that ADP rephosphorylation increases, reducing adenine degradation with consequent reduction of ammoniagenesis [28]. It has been shown to increase peak strength, mean power output, total work output and peak torque, as well as performance in young adults in a variety of sports that utilize the ATP-PC energy pathway to a significant extent [13, 23].

Several studies have investigated the effects of Cr loading on strength, body mass, and muscle fiber hypertrophy. Stevenson and Dudley [27] reported that 7 days of Cr loading cannot improve maximum voluntary contraction, but there were significant differences between the Cr group and the placebo group in 1RM and 5RM of leg extension. Eckerson et al [9] reported that 2 days' loading successfully increased muscle stores, but not the anaerobic work capacity, in physically active women. Ziegenfuss et al [34] reported 3 days of Cr supplementation can increase thigh muscle volume and may enhance cycle sprint performance in elite power athletes; moreover, this effect is greater in females as sprints are repeated. Eckerson et al's latest study [8] on men and women documented increases in anaerobic work capacity after 2 and 6 days of Cr loading but no statistical significance when compared with the placebo group. Law et al [19] examined the effects of 2 and 5 days of Cr loading on muscular strength and anaerobic power in trained athletes, and found that a 5-day Cr loading regime coupled with resistance training resulted in significant improvements in both average anaerobic power and back squat strength compared with just training alone.

Although Cr supplements are commonly used by many athletes, our knowledge is limited on prescription of Cr loading. Regarding the effects of short-term Cr loading on performance, previous findings are still vague and controversial. In addition, few studies have also examined a Cr loading regime shorter than 7 days. Therefore, the purpose of this study was to determine the effects of 3, 5, and 7 days of Cr loading on strength, power, agility, sprint, and muscle size in young athletes.

MATERIALS AND METHODS

SUBJECTS

Twenty males were randomly divided into the creatine (Cr) or the placebo (Pl) group (Cr = 10; 21.57±1.13 years, Pl = 10; 20.0±1.15 years). The subjects were physically active (recreational resistance or aerobic training) and free of Cr supplementation at least one year prior to the beginning of the study. All subjects were required to read and complete a medical history form to ensure that eligibility criteria were met. All subjects were informed of the purpose and possible risks involved in the investigation and were required to read and sign an informed consent prior to participation. All procedures were approved by the University of Bukan Human Investigation Committees. The subjects' characteristics are provided in Table 1. There were no significant differences between Cr and Pl in age, body mass, height, and body fat at pretest.

Table 1. Subjects' characteristics (Means ± SD)

Variables	Cr (n = 10)	Pl (n = 10)
Age (y)	21.57±1.13	20.0±1.15
Body Mass (kg)	74.61±4.23	74.22±4.87
Body Height (cm)	178.30±8.10	181.43±7.31
Body Fat (%)	11.93±1.38	13.13±1.65

Cr = creatine; Pl = placebo.

PROCEDURES

The study subjects reported to the gymnasium on 8 separate days: 1 session of familiarization (to eliminate any learning effects on test performance) with testing and training, 3 sessions of resistance training (day 3, day 5, and day 7), and 4 sessions of testing (baseline, day 4, day 6, and day 8). At each testing session, body mass and body fat were obtained. There was a 24-hour rest between the familiarization session and the baseline testing. All resistance training sessions were performed at 4 PM. Testing sessions started at 10 AM. Before and after Cr loading, strength, power, agility, sprint, and muscle size were evaluated.

SUPPLEMENTATION PROCEDURE

The Cr group consumed 20g Cr monohydrate (Creatine Fuel, Twin Laboratories, Inc., Hauppauge, NY) for 7 days, whereas the Pl group consumed 20g dextrose for 7 days. The subjects were instructed to mix 5g Cr or dextrose with 300 ml of grape juice 4 times per day (8 AM, 1 PM, 6 PM, and 23 PM). The supplement was distributed premixed in resealable baggies containing instructions for consumption for the week. All subjects returned empty baggies on the day of posttesting and verbally confirmed consuming the supplement according to instructions. The subjects were informed not to make any significant changes to their diet during the testing or training program over the course of the study. The subjects were also asked to maintain their normal level of daily activity.

RESISTANCE TRAINING PROGRAM

The subjects performed resistance training at day 3, day 5, and day 7 (one day before the testing session). During each training session, the subjects performed 3 sets of 9 exercises (bench press, shoulder press, lat-pull down, arm curl, leg press, leg extension, leg curl, squat, abdominal crunches, respectively) with 10 repetitions. The intensity of the training program was determined at 75 or 85% of 1RM. One minute rest between attempts was provided for each subject. The subjects were not allowed to increase lifting the load during training. The resistance training protocol for Cr and Pl groups is presented in Table 2.

TESTING

The measures in this study consisted of percent body fat, muscle size in arm and thigh, standing long jump, 4 × 9-m shuttle run, 45-m sprint, and 1 repetition maximum (RM**)** strength for bench press, arm curl, and back squat, respectively. The procedure used for assessing 1RM was described by Kraemer and Fry [17]. The subjects performed a warm-up set of 8-10 repetitions with light weight (approximately 50% of 1RM).

The second warm-up consisted of a 3-5 repetitions set with moderate weight (approximately 75% of 1RM), and the third warm-up included 1-3 repetitions with heavy weight (approximately 90% of 1RM). After the warm-up, the subjects performed 1RM strength by enhancing the load on consecutive trials until the subject was unable to properly perform a good lift, complete the range of motion and correct the technique. Three- to 5-minute rest between the attempts was provided for each subject. In the 45-m sprint test, the subjects performed 2 maximal effort sprints over the distance of 45 m. The 45-m sprint test was performed on a hard even surface on an outdoor track. The subjects had standing start position on the start line, and on command they ran a 45-m sprint as fast as possible over the distance. When they crossed the finish line, the time was stopped on the handheld stopwatch (Joerex, ST4610-2). The sprints were separated by a 3-4-minute period to ensure full recovery between trials. The shuttle run test was included as a measure of the ability to sprint and change direction. With the 4×9-m shuttle run, the subjects stood behind the starting line and on command, they started the 9-m run. At the end of the 9-m section, the subjects were asked to stop with 1 foot beyond a marker while reversing the running direction and sprinting back to the start where the same reversing of movement direction was required. After the fourth 9-m section, when the subjects crossed the finish line the time was stopped. The better of 2 consecutive trials was used for the statistical analysis. Three minutes' rest between attempts was provided for each subject. The standing long jump was used as a test of bilateral leg power and performed with both legs together. Arm movements were permitted for support during the take-off movements. Trials were only evaluated when the subjects landed properly on their feet while not falling back. The distance between the toes at start and the heels at landing was used as a testing criterion. The better of 2 consecutive trials was used for the statistical analysis [16].

Table 2. Resistance training protocol

Exercises	Sets	Reps
Bench press	3	10
Shoulder press	3	10
Lat-pull down	3	10
Arm curl	3	10
Leg press	3	10
Leg extension	3	10
Leg curl	3	10
Squat	3	10
Abdominal crunches	3	10

Arm muscle cross-sectional area (MCSA) was estimated using the equation by Frisancho [11]: Arm MCSA = [arm circumference (mm)] / π × [skin fold thickness at the arm (mm)]. Thigh muscle cross-sectional area (MCSA) was estimated using the equation by Housh et al [14]: Thigh MCSA = [4.68 × circumference of mid-thigh (mm)] - [2.09 × skin fold thickness at the thigh (mm)] - 80.99. Each subjects' weight and 3-site skin fold thickness was measured at baseline, day 4, day 6, and day 8. The subjects had 3 skin fold sites (chest, abdominal, and thigh) measured to determine body composition or body fat percentage. The measurement was used according to the method by Jackson and Pollock [15]. All skin fold measurements were taken using Lafayette caliper (Skin Fold Caliper, Model 01127-INDIANA). Skinfold thickness was based on the average of the two trials. If the two skinfold measurements at the same site differed by more than 0.5 mm, a third measurement was obtained and the mean value used. The subjects had a 5-min rest in between functional performance tests.

STATISTICAL ANALYSIS

All data are presented as Mean ± SD. Statistical analysis was performed using SPSS version 16.0 software. Analysis of variance (ANOVA) with repeated measures by Bonferroni post hoc testing was used to determine significant differences within the groups. The independent sample *t*-test was used to identify any significant differences between the groups. The level of significance was set at $p \leq 0.05$.

RESULTS

There were significant differences at 3, 5, and 7 days of Cr loading in contrast to baseline at 1RM bench press (mean differences [MD]; 2.2±0.4, 3.9±0.6, 4.7±1.0 kg, respectively, $p < 0.05$) (Figure 1; A). There were also significant differences among 3, 5, and 7 days of Cr loading compared with baseline, as well as between 3 days with 5 and 7 days for 1RM back squat (MD; 3.5±0.6, 7.0±1.3, 7.5±1.2, 3.5±0.6, 4.0±1.1 kg, respectively), arm curl (MD; 2.5±0.5, 6.0±0.9, 6.0±1.0, 3.5±0.5, 3.5±0.6 kg, respectively), and standing long jump (MD; 0.11±0.01, 0.16±0.21, 0.10±0.20, 0.04±0.01, 0.05±0.01 cm, respectively) ($p < 0.05$) (Figure 1; B, C, D). In the 45-m sprint test, the Cr group significantly differed at 5 and 7 days compared with baseline, as well as 3 days of Cr loading (MD; -0.29±0.06, -0.26±0.07, 0.22±0.06, 0.20±0.07 sec, respectively, $p < 0.05$) (Figure 1; E).

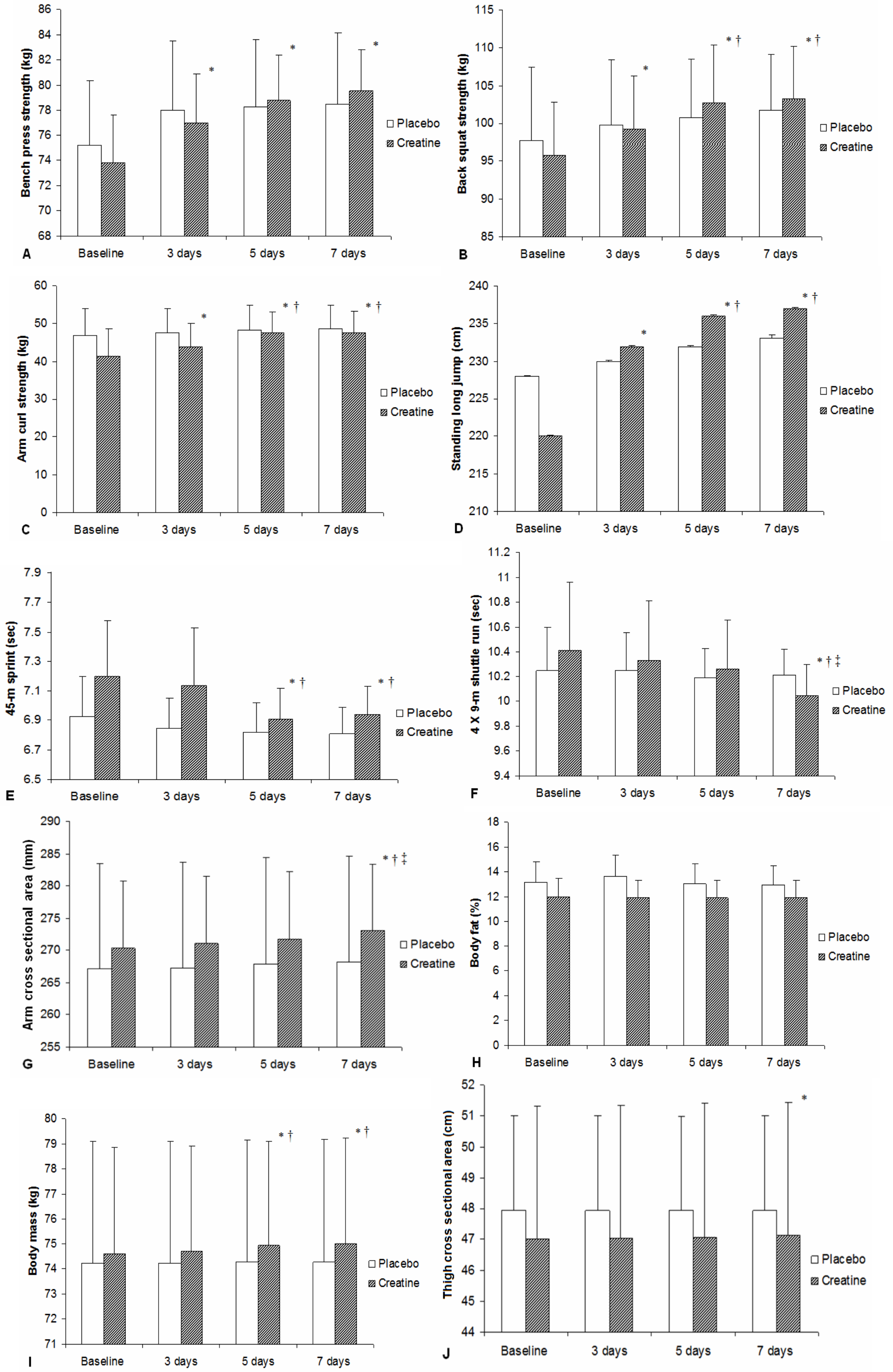

Figure 1. (A, B, and C) one repetition maximum testing for bench press, back squat and arm curl; (D) standing long jump; (E) A 45-m sprint test; (F) 4 × 9-m shuttle run; (G) cross-sectional area of the arm; (H) percent body fat; (I) body mass; (J) cross-sectional area of the thigh. Values are mean ± SD

* Significantly different ($p < 0.05$) from the corresponding baseline
† Significantly different ($p < 0.05$) from the corresponding 3 days of creatine loading
‡ Significantly different ($p < 0.05$) from the corresponding 5 days of creatine loading

The Cr group showed significant improvement at 7 days from corresponding baseline; there were also significant differences between 3 and 5 days of Cr loading compared with 7 days in 4×9-m shuttle run (MD; -0.36±0.09, -0.28±0.08, -0.21±0.05 sec, respectively) and arm hypertrophy (MD; 2.7±06, 2.0±0.5, 1.3±0.2 cm, respectively) ($p < 0.05$) (Figure 1; F, G). There were no significant changes in body fat at 3, 5, and 7 days of Cr loading ($p > 0.05$) (Figure 1; H). However, body weight increased at 5 and 7 days significantly (MD; 0.33±0.09, 0.39±0.9 kg, respectively, $p < 0.05$). In addition, there were significant differences between 3 days and 5 and 7 days of Cr loading (MD; 0.21±0.01, 0.27±0.02 kg, respectively, $p < 0.05$) (Figure 1; I). For thigh muscle hypertrophy, the Cr group showed significant difference at 7 days of Cr loading compared with baseline (MD; 2.8±0.8 cm, $p < 0.05$) (Figure 1; J).

DISCUSSION

Our investigation is unique because, to our knowledge, it is the first study to compare the effects of 3, 5, and 7 days of Cr loading on skeletal muscle volume and functional performance. We found that muscle strength improved during back squat, arm curl, and bench press following 3, 5, and 7 days of Cr loading. There were also significant differences between 5 and 7 days of Cr loading in contrast to 3 days of Cr loading at back squat and arm curl. These findings are in line with Rossouw et al [25], who reported significant improvements in 1RM dead lifts after 5 days of supplementation. Volek et al [31] randomly assigned nineteen healthy resistance-trained subjects in a double-blind fashion to either a Creatine supplementation (CrS) or placebo for 7 days, and found that increases in bench press and back squat were greater in the CrS group than in placebo. These findings are in agreement with the present study. In contrast, Vandenberghe et al [29] compared knee extension torque production during maximal intermittent tests conducted after 2 days and 5 days of Cr supplementation, and reported that 2 days of Cr loading increased muscle phosphoscreatine (PCr) content and significantly improved torque production by 5 to 13%. Also, Stevenson and Dudley [27] suggested that Cr loading does not augment unilateral strength or multiset resistance exercise performance for knee extensions compared with placebo loading. The findings of the present study are in agreement with Law et al [19] who found no statistically significant difference in 1RM bench press or back squat strength after 2 days of CrS compared with baseline. However, they found significant increases in 1RM back squat between 2 and 5 days of Cr loading. In the present study, we found that more than 3 days of Cr loading is required to achieve an increase in muscle strength; also more than 5 days of Cr loading is a period sufficient for improving muscle strength at arm curl and back squat. It is believed that more than 5 days can increase content of muscle PCr and improve muscular strength performance.

In standing long jump, the results indicated significant increases at 3, 5, and 7 days of Cr loading in contrast to baseline. Significant differences were observed at 5 and 7 days rather than 3 days of Cr loading. To our knowledge, no study examined the effects of acute CrS on explosive power. We also found significant improvement in standing long jump after 3 days Cr loading, approximately 10 cm. This increase can be due to availability of PCr in the muscle fibers before the standing long jump. Moreover, ATP-CP system is a major component for realizing energy during power test, and Cr loading can enhance this potential. Although muscle phosphagen concentrations were not directly measured in the current study, it is possible that the observed increases in standing long jump for the Cr group were caused by increases in intramuscular stores of total Cr and PCr [1, 22].

Significant improvements were found after 7 days of Cr loading in contrast to the baseline, 3, and 5 days in 4 × 9-m shuttle run. It appears that 7 days of loading may be superior to 3 and 5 days for improving agility in males. It is believed that 7 days can enhance total muscle PCr and consequently improve agility performance.

The data in this investigation demonstrated that 5 and 7 days' CrS significantly improved 45-m sprint performance. These findings are in line with Mujika et al [21], who examined the effects of 5 and 7 days of Cr loading on sprint performance and found significant improvement in sprint in male soccer players. The results from Dawson et al [6] indicated that CrS (20 $g\cdot day^{-1}$ for 5-d) significantly increased work performed during the first of 6 × 6 s cycle ergometer sprints with 30 s recovery between sprints. These results support Schneider et al [26], who reported that CrS (25 $g\cdot day^{-1}$ for 7-d) significantly improved 5 × 15 s cycle ergometer sprints with 60 s recovery between sprints. In contrast to the current study, Bruck et al [4] indicated that CrS (20 $g\cdot day^{-1}$ for 5-d) did not enhance performance in maximal single effort swim sprints of 25 m, 50 m, and 100 m with 10 min recovery period between each. Moreover, Delecluse et al [7] investigated the impact of short-term (7-day), high-dose (0.35 $g\cdot kg^{-1}\cdot day^{-1}$) CrS on single sprint running performance (40 m) and on intermittent sprint performance in highly trained sprinters. They found no significant changes related to CrS in absolute running velocity at any distance between start and finish (40 m). CrS may be useful in sports such as volleyball and basketball that require repeated sprint efforts and CrS may be advantageous as an aid improving both training and performance [3]. The ergogenic effect of CrS in a single sprint will result from better maintenance of a high power output towards the end of the sprint. Thus, total work is expected to increase and the power or speed decline during the sprint may be reduced following CrS [5]. Furthermore, the possible increase in muscle mass and fiber area after CrS and training may act independently to improve sprint performance [5].

No changes in body fat were observed for either the Cr group or the placebo group during the entire experimental period, while body mass of the Cr group increased significantly after 5 and 7 days of Cr loading. Short term CrS has been shown to increase total body mass by 0.7-1.6 kg [2, 10, 29]. Law et al [19] addressed significant increases in body mass of 0.84 kg in the Cr group compared with placebo after 5 days of supplementation. The lack of change in skin fold thickness after CrS suggests that the increase in body mass is due either to an increase in fat-free mass and/or an increase in total body water. The analysis of thickness did not allow us to determine which of these components contributed to the increase in body mass; although body composition was not assessed in the present investigation, most research studies attribute increases in body weight following short-term CrS to an increase in body water, and more specifically, to an increase in the volume of the inter-cellular compartment [3, 31, 34].

The data indicated that 7 days of CrS can increase thigh and arm muscle volume. In contrast to the present study, Ziegenfuss et al [34] reported that 3 days of Cr loading can enhance thigh volume in elite power athletes. The important question is, what accounts for the increase in muscle volume: water, protein, or a combination of both? Prior investigation used multifrequency bioimpedance analysis to assess changes in body fluid compartments after CrS, and suggested that approximately 90% of the weight gain associated with the initial days of CrS can be accounted for by increases in total body water, and that much of this increase is contained within the intracellular compartment, at least when Cr is congested with a high glycemic index beverage [34, 35].

CONCLUSION

In summary, the present study indicated that a 5 and 7 days' Cr loading regime coupled with resistance training resulted in significant improvements in cross-sectional area, body weight, and agility. Although 3 days' Cr loading is sufficient for improving standing long jump and strength, 5 and 7 days' Cr regime were better than 3 days in standing long jump, 1RM arm curl and bench press. Therefore, 7-day loading regime should be prescribed to individuals supplementing with Cr for enhanced performance.

PRACTICAL APPLICATION

Athletes participating in a resistance training program may benefit from creatine supplementation because the it allows them to complete their physical performance. Furthermore, athletes for whom an increase in body mass would be advantageous may also benefit from creatine ingestion. We recommend that athletes should use 3 days' creatine supplementation for improving strength, 5 days' CrS for enhancing body weight and power, and specially 7 days' CrS for agility and arm cross-sectional area.

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