The Effect of Continuous Low Dose Creatine Supplementation on Force, Power, and Total Work

Darren G. Burke, Shawn Silver, Laurence E. Holt, Truis Smith-Palmer, Christopher J. Culligan, and Philip D. Chilibeck

Dietary supplementation (SUP) has become a significant part of athletic training. Studies indicate that creatine (Cr) can enhance short-duration, high-intensity activities. This study examined the effect of 21 days of low dose Cr SUP (~7.7 g/day) and resistance training on force output, power output, duration of mean peak power output, and total work performed until fatigue. A double-blind protocol was used, where an individual, who was not part of any other aspect of the study, randomly assigned subjects to creatine and placebo groups. Forty-one male university athletes were randomly assigned to either Cr (n = 20) or placebo (n = 21) SUP. On the first and last day of the study, subjects were required to perform concentric bench press movements until exhaustion on an isokinetic dynamometer. The dynamometer was hard-wired to a personal computer, which provided force, velocity, and duration measures. Force and power output until fatigue, were used to determine total work, force-time, and power-time relationships. ANOVA results revealed that the Cr subjects performed more total work until fatigue, experienced significantly greater improvements in peak force and peak power, and maintained elevated mean peak power for a longer period of time. These results indicate that Cr SUP can significantly improve factors associated with short-duration, high-intensity activity.

Key Words: fatigue, endurance, ergogenic aids, bench press, sports nutrition, exercise

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Creatine (Cr), when phosphorylated, is important for the buffering of energy within skeletal muscle: phosphocreatine (PCr) serves to rephosphorylate adenosine diphosphate, keeping adenosine triphosphate levels constant during muscular contraction (3). An optimal PCr concentration is important for sustaining force production during muscular work (10).

The beneficial effects of dietary Cr supplementation on exercise performance have been studied thoroughly in the past few years. Short-term supplementation may increase formation and storage of PCr within skeletal muscle (7, 11, 25) and has been shown to enhance work output, especially during repeated bouts of high-intensity exercise (1, 6).

Skeletal muscle Cr uptake is enhanced if Cr supplementation is combined with exercise (7). This implies that for optimal enhancement of performance, Cr supplementation should be combined with training. When combined with exercise training, Cr supplementation has been shown to enhance exercise performance more so than exercise training alone (2, 4, 15, 17, 24, 25) or Cr supplementation alone (2).

Creatine doses used during most training studies are based on those found to result in optimal elevation of muscle Cr stores, assessed by the needle biopsy technique (11). This involves dosing of approximately 20 g of Cr per day for 5 days (termed a muscle “loading” phase), followed by a “maintenance” dose of approximately 5–10 g per day thereafter (4, 24, 25). Creatine supplementation using these doses has anecdotally been reported to result in side effects such as diarrhea, dehydration, muscle cramping, and gastrointestinal pain in some individuals (14); therefore, a regimen that involves lower dosing (<20 g/day) may be preferable. It has been shown that skeletal muscle Cr stores can be elevated to similar levels following 28 days of a lower dose (3g/day), compared to the above-mentioned loading schedule (11); however, the effectiveness of a lower-dosing regimen combined with exercise training has not been thoroughly investigated. The purpose of this study was therefore to investigate the effects of a lower-dose Cr regimen combined with resistance training on muscular performance in young strength-trained males. We chose to use a 21-day duration training program, as this is the approximate mean duration of previous studies that have shown positive effects of higher doses of Cr supplementation combined with resistance training, in a similar subject population (4, 15, 17, 24, 26). In this study, we used a Cr dose of approximately 7.7 g/day, as this is intermediate to a dose of 3 g/day, which does not result in complete Cr saturation of muscle within 14 days (11), and a dose of 10 g/day, which is the minimal dose thus far shown to be effective for improving muscular performance (17). We chose a creatine dose closer to 10 g/day rather than the mean of 3 g/day and 10 g/day, because the effectiveness of lower-dosing regimens have not previously been investigated; therefore, we wanted to err on the side of caution. We hypothesized that this dosing regimen, when combined with 21 days of resistance training, would enhance muscular performance more so than training alone.

Methods

Subjects

Forty-seven male university athletes were recruited from the university athletic program. Subjects had not supplemented with creatine within the previous 6 weeks.
This is greater than the length of time (30 days) required for washout of creatine from muscle (11). All subjects were familiar with weight training and had a minimum of 3 years experience. Each subject signed an informed-consent form and was free to withdraw from the study at any time. This study was approved by the university's ethics review committee for research involving human experimentation. A double-blind protocol was used, where an individual, who did not participate in any other aspect of the study, randomly assigned subjects to creatine (Cr; n = 24) or placebo (P; n = 23) groups. Six subjects (4 Cr and 2 P) were dropped from the study because they missed more than one dose of daily supplement or more than one workout session. Subject characteristics are presented in Table 1. There were no significant differences between groups for any baseline measures.

All participants were instructed to train following a specific exercise program using free weights for the duration of the study. The exercise program consisted of a modified periodization strength training protocol designed to increase strength and power in the shoulder girdle musculature (18, 23). Training involved bench press, military press, and tricep exercises performed every second day, for a total of 11 workouts in the 21-day period. The 11 training sessions were performed accordingly: Sessions 1–2, 4 sets × 15 repetitions; Sessions 3–5, 5 sets × 10 repetitions; Sessions 6–8, 6 sets × 6 repetitions; and Sessions 9–11, 4 sets × 10 repetitions. The last set of each exercise was performed at 50% of 1-RM until exhaustion. Subjects trained in groups of 2–4, and the weight used was specific to each individual and his progress, and adjusted so he could complete the designated sets and repetitions.

Dietary intake was not monitored; however, the majority of subjects (88%) lived in campus dormitories and ate the same food in the cafeteria. Fluid intake was not measured, but subjects were encouraged to consume between 8–12 large glasses of water per day.

Table 1  Subject Characteristics Before and After Training

<table>
<thead>
<tr>
<th>Variables</th>
<th>Creatine group</th>
<th>Placebo group</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre-training</td>
<td>Post-training</td>
</tr>
<tr>
<td>Age (years)</td>
<td>21 ± 2</td>
<td>21 ± 2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.1 ± 7.0</td>
<td>179.1 ± 7.0</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>89.8 ± 17.1</td>
<td>92.0 ± 17.8*</td>
</tr>
<tr>
<td>Chest girth (cm)</td>
<td>106.8 ± 12.2</td>
<td>107.6 ± 11.9*</td>
</tr>
<tr>
<td>Arm girth (cm)</td>
<td>35.3 ± 4.6</td>
<td>36.0 ± 3.7*</td>
</tr>
<tr>
<td>Thigh girth (cm)</td>
<td>54.6 ± 7.5</td>
<td>57.9 ± 7.6*</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>76.3 ± 14.8</td>
<td>78.5 ± 15.1*</td>
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</tbody>
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*Significantly different from pre-training value (p < .05).
Experimental Design

One week prior to the onset of the study, subjects were given two training sessions on the testing apparatus. The piece of equipment used was a pseudoisokinetic device set up to isolate concentric bench press movements only. Strain gauges connected to the resistance unit provided quantification of the force applied to the moveable arm and a variable resistor fixed to the moveable arm provided velocity readings. A complete description of this device and its application for testing can be found elsewhere in the literature (9). Vernier apertures were set to provide a maximum velocity of 1.143 m/s for the bench press movement, while an open aperture setting was used to provide zero resistance for the bench row return motion. The dynamometer’s hard-wired PC connection provided force and velocity measures, which were processed through an A/D data acquisition board (National Instruments, USA) and analyzed using Biobench Physiological Data Acquisition and Analysis Software (National Instruments, USA). Reliability previously assessed for this testing device in our lab indicated an intraclass correlation of $R = 0.98$.

On the day before supplementation and the last day of the study, subjects were required to perform maximal continuous concentric only bench press and bench row movements until exhaustion. Force-time, power-time, and velocity data were recorded for each subject. Total work output was calculated through the integration of the power-time curve from the start of the test until there was a 30% decline in mean peak power (MPP) output. The time until this 30% decline in MPP was recorded and used as a marker of fatigue.

Creatine Supplementation

Anthropometric and skinfold values were collected for each subject to determine percent fat and LBM (22). The same fitness appraiser performed all skinfold measures using calibrated Harpenden Skinfold Calipers (British Indicators, UK). Cr supplementation and weight training started the day following pretest measures and continued for 21 consecutive days. Each day, subjects reported to a private room to receive a dose of either placebo or creatine mixed with warm grape juice. The placebo consisted of warm grape juice only, while the creatine group received the same warm grape juice with the addition of 0.1 g/kg LBM of pure creatine (Nutrition Health and Fitness, Toronto). Creatine dosages were based on subjects’ LBM, because 95% of the total body creatine pool is located in skeletal muscle (12). It has previously been recommended that doses be based relative to body size (11). Absolute doses in our subjects averaged 7.7 g/day. The creatine supplement was indistinguishable from placebo in taste, texture, and color. The entire daily dosage was consumed in one single serving, and subject compliance was 87%. Daily supplements were prepared by four senior nutrition students, who were not involved in any other aspect of the study, and all supplement beverages were prepared immediately prior to consumption.

Statistical Analysis

An SPSS-PC statistical package was used to perform an analysis of variance procedure to assess differences between groups (Cr and P) for each of peak force, peak power, total work, and duration of mean peak power output (MPP), and within
groups for pre and post-test results. Tukey’s post hoc comparisons were performed to identify significant differences between pairs of means. Significance in this study was set at the .05 level.

Results

Results revealed that both the creatine and placebo group experienced significant increases in peak force (Figure 1) and peak power output (Figure 2), and that the changes demonstrated by the creatine group were significantly greater than those of the placebo group. Peak force and peak power were significantly increased by 23% and 21%, respectively, for the creatine group and by 13% and 12% for the placebo group, following the training program. The creatine group experienced a significant 46% improvement in time to fatigue, while changes were not significant in the placebo group (Figure 3). The creatine group significantly increased total work by 68% ($p < .05$), while the placebo group experienced an increase of 16% (Figure 4). The average number of repetitions performed until exhaustion for the creatine group was 17 (pre) and 24 (post); whereas, the average number of repetitions performed by the placebo group was 19 (pre) and 20 (post). The increased number of repetitions performed by the creatine group was significant at the .05 level.

The creatine group experienced significant increases in all anthropometric measures except percent fat, whereas no statistically significant changes occurred for placebo group subjects. The mean change in body mass was 2.2 kg ($p < .05$) for

![Figure 1 — Changes in peak force (N) pre- and post-training in creatine-supplemented (creatine) and placebo-supplemented (placebo) groups. Note: Error bars are standard deviations. *Significantly different from pre-training ($p < .05$). **Change over time is significantly greater in creatine-supplemented versus placebo group (group × time; $p < .05$).](image-url)
Figure 2 — Changes in peak power (W) pre- and post-training in creatine-supplemented (creatine) and placebo-supplemented (placebo) groups. Note: Error bars are standard deviations. *Significantly different from pre-training ($p < .05$). **Change over time is significantly greater in creatine-supplemented versus placebo group (group $\times$ time; $p < .05$).

Figure 3 — Changes in fatigue resistance (time until 30% decline in mean peak power output) pre- and post-training in creatine-supplemented (creatine) and placebo-supplemented (placebo) groups. Note: Error bars are standard deviations. *Significantly different from pre-training ($p < .05$). **Change over time is significantly greater in creatine-supplemented versus placebo group (group $\times$ time; $p < .05$).
Figure 4 — Changes in total work (kJ) pre- and post-training in creatine-supplemented (creatine) and placebo-supplemented (placebo) groups. Note: Error bars are standard deviations. *Significantly different from pre-training ($p < .05$). **Change over time is significantly greater in creatine-supplemented versus placebo group (group × time; $p < .05$).

creatine subjects and 0.5 kg for placebo subjects. The creatine group significantly increased chest girth by 0.8 cm ($p < .05$), arm girth by 0.7 cm ($p < .05$), and mid-thigh girth by 3.3 cm ($p < .05$). Table 1 lists pre- and post-training anthropometric measurements for both the creatine and placebo group.

**Discussion**

To our knowledge, this is the first study to show that a Cr dose as low as 7.7 g/day can enhance the effectiveness of resistance training. Lower doses of Cr may be preferred by some athletes, as higher doses may be associated with various side effects (14). Our results are similar to other studies that demonstrated positive effects of higher doses of Cr supplementation combined with resistance training in strength-trained males. With our lower dose, Cr-supplemented subjects demonstrated increases of 23% for peak force (compared to a 13% increase for placebo), 21% for peak power (compared to 12% for placebo), and 46% for time to fatigue (compared to 7% for placebo) during the bench press exercise. This is similar to studies using higher doses (10.5–21 g Cr/day) that demonstrated increases in bench press 1-RM of 6–12.9% and improvements in endurance (repeated lifting performance) of approximately 26% over a training duration of 28–56 days (4, 15, 24). Two studies of young strength-trained men using shorter training durations (5–6 days) and doses of 10–25 g Cr/day also demonstrated greater improvements in repeated bench press lifting (20% for a Cr-group vs. 6% for placebo) (26) and isometric strength and endurance.
Our results indicate that lower doses of Cr combined with training can enhance muscular performance to the same extent as higher doses.

In addition to a greater muscle performance, we found that estimates of increases in lean tissue were greater with training in Cr versus placebo groups (2.3% increase in Cr versus a 1.4% increase in placebo). Again, this is similar to results from studies that have used higher doses of Cr over similar time periods. Kreider et al. (15, 16) used doses of 15.75–20 g Cr/day for 4 weeks in resistance-trained males and demonstrated increases in lean tissue of 3.28–3.4% in Cr groups compared to 1.1–1.9% with placebo. Stout et al. (24) and Earnest et al. (4) found increases in lean tissue of 2–4.6% in their Cr groups compared to decreases of 0.4–0.6% for placebo groups over 4–8 weeks of training. Compared to these studies, our lower doses of Cr appear to be equally effective. It seems reasonable to attribute the significantly enhanced performance demonstrated by creatine subjects to be the result of the greater changes in lean body mass exhibited by those ingesting creatine supplements. It is well known that increased muscular size or cross-sectional area are positively correlated with increased strength and power outputs (20).

Our study, as well as those cited above, used resistance exercise training combined with Cr supplementation to enhance muscular performance, rather than using only Cr supplementation alone. Harris et al. (7) showed that Cr uptake into skeletal muscle is enhanced with exercise; therefore, this should enhance muscular performance more so than supplementation without exercise training. Only one study has investigated the effects of moderate-duration Cr supplementation alone, without training in humans (19). Following a dose of 20 g Cr for 10 days, and 4 g Cr for 20 days, a group of healthy, but older, men demonstrated an improvement in muscle fatigue but no improvement in muscular strength or lean tissue mass. One study in rats has shown that Cr supplementation combined with training enhances muscular performance and hypertrophy to a greater extent than either intervention alone (2). Studies in humans of the effects of Cr alone and that combined with resistance exercise are needed to demonstrate whether the effects of Cr are truly enhanced if combined with exercise training.

Differences in muscular performance between Cr-supplemented and placebo groups following training are most likely due to differences in hypertrophy of muscle. The skinfolds and girth measurements used in our study can only give a rough estimate of changes in muscle mass; however, others have demonstrated that Cr may stimulate muscle protein synthesis. Ingwall (13) demonstrated that Cr stimulates in vitro biosynthesis of muscle myosin, but Fry and Morales (5) failed to replicate these findings. It is also speculated that water retention during Cr supplementation (11) may act as a signal for protein synthesis within muscle cells (8). At the cellular level, Cr supplementation has been demonstrated to increase the size of type II muscle fibres in Cr-deficient patients (21). More study is needed on the possible mediators for increased lean tissue mass with Cr supplementation in healthy humans.

In summary, 21 days of Cr supplementation at a relatively low dose of 7.7 g/day or 0.1 g/kg LBM, can positively affect peak force output, peak power output, total work performed, and delay the onset of fatigue. These findings should be of great interest to those involved in sports requiring short bursts of high-intensity activity. A regular regimen of creatine supplementation in conjunction with a resistance exercise program can amplify the adaptations associated with this type of
training. The results evident in this study occurred at a supplement dosage much less than what has been reported in many other studies. Further research involving different dosage regimens and longer supplementation intervals is necessary to more fully understand the performance enhancing capabilities of this substance.

References


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