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HEALTH SCIENCES

Short term creatine loading improves strength endurance even without changing maximal strength, RPE, fatigue index, blood lactate, and mode state

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Abstract: Creatine is consumed by athletes to increase strength and gain muscle. The aim of this study was to evaluate the effects of creatine supplementation on maximal strength and strength endurance. Twelve strength-trained men (25.2 ± 3.4 years) supplemented with 20 g Creatina + 10g maltodextrin or placebo (20g starch + 10g maltodextrin) for five days in randomized order. Maximal strength and strength endurance (4 sets 70% 1RM until concentric failure) were determined in the bench press. In addition, blood lactate, rate of perceived effort, fatigue index, and mood state were evaluated. All measurements were performed before and after the supplementation period. There were no significant changing in maximal strength, blood lactate, RPE, fatigue index, and mood state in either treatment. However, the creatine group performed more repetitions after the supplementation (Cr: Δ = +3.4 reps, p = 0.036, g = 0.53; PLA: Δ = +0.3reps, p = 0.414, g = 0.06), and higher total work (Cr: Δ = +199.5au, p = 0.038, g = 0.52; PLA: Δ = +26.7au, p = 0.402, g = 0.07). Creatine loading for five days allowed the subjects to perform more repetitions, resulting in greater total work, but failed to change the maximum strength.

Key words: dietary supplements, muscle strength, physical endurance, resistance training, hypertrophy.

INTRODUCTION

Creatine (Cr) is a non-essential substance synthesized endogenously from reactions involving the amino acid arginine, glycine, and methionine in kidneys and liver or can be intake by diet from fish, meat, and poultry (Mills et al. 2020). It is one of the most studied, safe, and used nutritional supplements for athletes (Kreider et al. 2017). Along with caffeine, nitrate, beta-alanine, and sodium bicarbonate, creatine monohydrate is recognized as a nutritional ergogenic capable of directly improving physical performance (Maughan et al. 2018).

The effects of Cr on increasing muscle strength, training adaptations (e.g. muscle gain), and performance in high-intensity exercise have been shown (Cooper et al. 2012, Kreider et al. 2017, Lanhers et al. 2016). Acute or prolonged Cr supplementation enhances muscle stores by 20-40% which potentiates the effects of Cr on physical performance (Hultman et al. 1996, Kreider et al. 2017). Sportspeople engaged in resistance training and strength athletes commonly use creatine supplementation to improve muscle hypertrophy and strength.

The rise of creatine and phosphocreatine (PCr) muscle stores is responsible for the effects of creatine including higher adenosine triphosphate (ATP) resynthesis from PCr, faster regeneration of PCr during exercise recovery, and enhanced ATP production from glycolysis secondary to increased hydrogen ion buffering (Lemon 2002). Thus, Cr supplementation favors the maintenance of efforts at higher intensities and adaptations to training. In this context, creatine combined with physical exercise has been shown to improve the performance of athletes involved in intense anaerobic activities (Zuniga et al. 2012).

The training volume performed in a resistance training session plays a significant role in chronic muscular adaptations, such as muscle size and strength (Schoenfeld et al. 2019). Performing a large number of repetitions per set promotes high metabolic stress, which, when combined with a moderate intensity performed until failure, may be a key factor in stimulating acute growth hormone secretion and therefore contributing to hypertrophy (Willardson et al. 2010). The theory that repetitions performed until failure are superior in promoting muscle development influences a large number of athletes, including bodybuilders who use failure training in their programs (Davies et al. 2016).

Resistance training is the primary intervention for increasing muscle hypertrophy in humans (Schoenfeld et al. 2019). Additionally, resistance training combined with Cr supplementation has generally been shown to be more effective in promoting muscle mass gains compared to resistance training alone (Ribeiro et al. 2020).

This study aimed to compare the effect of Cr supplementation or Placebo on maximal dynamic strength and strength endurance compared to the control (no treatment). We hypothesized that just Cr supplementation (true creatine) would significantly increase the maximal dynamic strength and strength endurance compared to the control (no treatment).

MATERIALS AND METHODS

Participants

Twelve strength-trained healthy men (see Table I) with 18 to 30 years volunteered in this study. All participants had at least three years of experience in resistance training (weight training) and none reported using nutritional supplements or anabolic steroids last three months. Volunteers were informed about each experimental procedure, the number of visits, risks, and benefits for them. They were also informed that they could withdraw from the study at any time. Experimental procedures were approved by the Universidade Federal de Lavras Ethics Committee (number: 2.984.792) in accordance Declaration of Helsinki and each participant provided written informed consent before starting the experimental procedures.

All volunteers were recreational weight trainers who consumed non-vegetarian diets and none of them reported using nutritional supplements or medications. Throughout the experimental period, they were instructed not to change their habitual diet or physical activity routine.

Table I. Participants characteristics.

Variable	Mean ± SD
Age (years)	25.2±3.4
Height (cm)	179.5±4.6
Body weight (kg)	84.9±8.7
Body fat (%)	14.8±6.0
Skeletal muscle mass (kg)	41.8±4.0
Total body water (kg)	52.8±4.6
RT experience (years)	5.9±3.1
Training sessions (session/week)	5.0±0.6
Session duration (min.)	64.2±17.8
1RM bench press (kg)	106.8±10.6

RT = Resistance training
1RM = Maximal dynamic strength.
Data are presented as mean ± SD.

Study design

The study comprises a randomized crossover, double-blind, placebo-controlled design, subjects are informed that they will receive either the positive substance/treatment or a placebo.

Participants visited the laboratory on five occasions. The first visit was to familiarise participants with the procedures of research. Familiarization sessions included dietary records, anthropometrics, rating perceived exertion (RPE), blood lactate, maximal dynamic strength (1RM), and strength endurance tests. Participants were randomized to receive creatine or a placebo for five days separated by at least thirty days (Fig. 1). On the visit two participants repeated all tests and measurements (day 1=pre) and received either creatine or placebo. They were instructed to start supplement consumption on the following day (day 2) until day six. On day 7 (post) the participants returned to the laboratory (visit 3) and performed all the tests and measurements again. After at least thirty days the participants repeated all procedures described for visits two and three reversing the treatments (visits 4 and 5).

Diet and anthropometrics

Height was assessed using a calibrated stadiometer (Sanny ES2030). The weight and body composition were measured using electrical bioimpedance from In Body 230 multifrequency analyzers, which use the tetrapolar 8-point tactile electrode method. Anthropometrics data were collected in visit 1. Participants were asked for no change in their dietary habits throughout the study. Dietary intake was assessed by a nutritionist using a 24-hour food diary collected on pre-test days. Participants were instructed

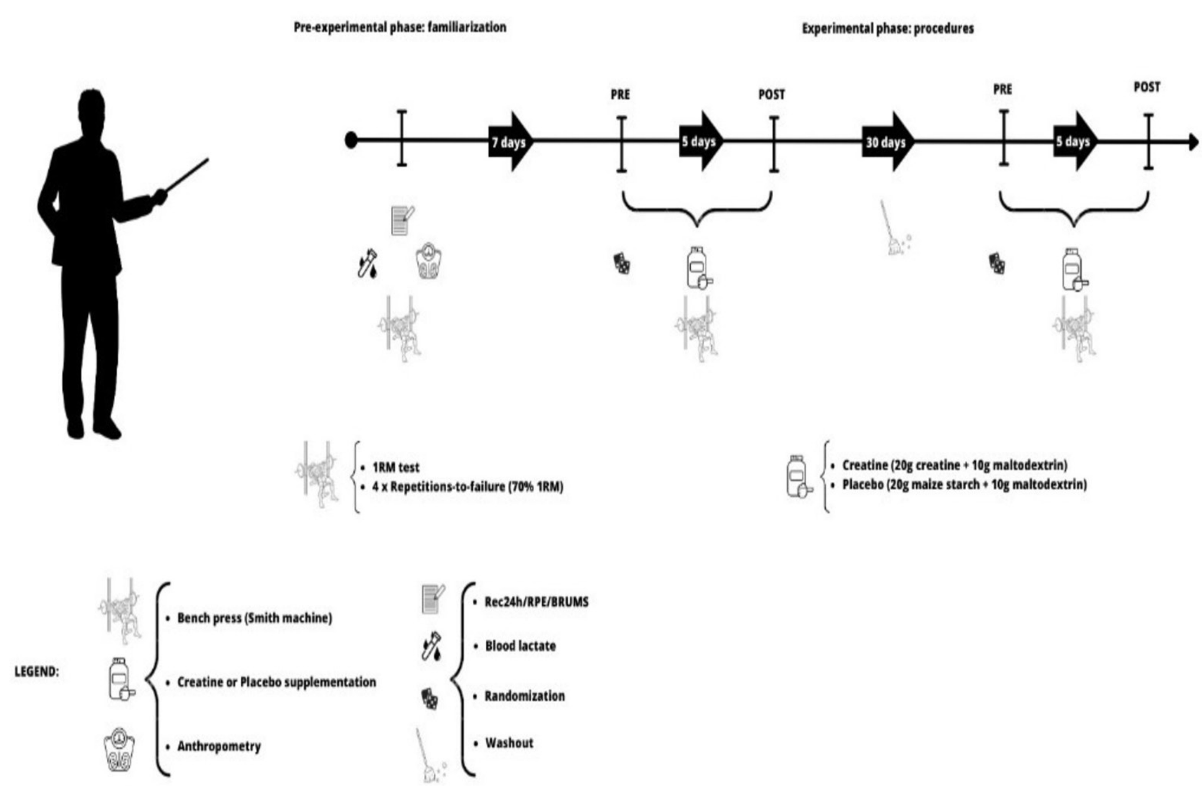

Figure 1. Experimental Design.

to repeat the same diet in the days before the tests. The food diaries were analyzed using the DietBox® software.

Supplementation protocol

All participants had previously consumed creatine but had not used it in the three months before the study. Following random assignment participants receive creatine (Cr) or a placebo using a loading protocol for five days. The creatine group received five pots each one containing 20g of micronized creatine monohydrate + 10g of dextrose lemon flavour properly homogenized. The placebo was composed of 20g of maize starch + 10g of dextrose lemon flavor. The supplements were mixed until a homogeneous mixture was obtained. The researchers tested various proportions until they got a mixture that looked and tasted similar after diluting it with water. Participants were instructed to consume 4 servings of 7.5g (≅ 2 spoons) per day diluted in approximately 400 mL of water using a mug provided by the researchers after meals.

Maximal dynamic strength (1RM) and strength endurance (resistance training)

The maximal dynamic strength (1RM) for the bench press exercise was performed on a Smith Machine Physicus® with participants lying horizontally. The procedures followed methods from the National Strength and Conditioning Association guidelines for maximal strength testing (Haff & Triplett 2015). Participants were asked to refrain from strenuous exercise and alcohol intake for 24 hr before all trials. To prior the 1RM assessments, the subjects completed a standardized warm-up consisting of 2 sets of light-weight. During sets, the load was progressively increased until subjects reach 1RM attempt. The subjects were given 3-minute rest between warm-ups. The repetition was considered successful when subjects lowered the bar to their chest during the eccentric phase and returned to a full extension during the concentric phase. The 1RM determinations were made within 3 to 5 attempts.

After at least ten minutes later the maximal strength test, participants completed a strength endurance test. The protocol to assess strength endurance was composed of four sets until concentric failure at 70% 1RM in the bench press (same Smith machine used 1RM), with cadence 1:1s, separated by 1 minute of interval. Participants were instructed to perform repetitions to failure. The sets were stopped when the participants were unable to perform the complete movement at the proposed cadence and/or technique. Performance was evaluated by the number of repetitions performed and the total work (repetitions x load).

Rating perceived exertion (RPE)

The rating of perceived exertion from the OMINI-RES 0-10 scale was recorded immediately after the strength endurance test (Morishita et al. 2018).

Fatigue index

The fatigue index (FI) was used to determine the decline in force produced over time (Ribeiro et al. 2014). The rate of force reduction between the first and fourth series of the horizontal supine exercise was used as an indicator of fatigue, according to the formula proposed by Sforzo & Touey (1996) IF = [(FT(1st series) - FT(4th series)/ FT(1st series)] x 100%, where IF stands for fatigue index and, FT is equal to total force (load lifted times the number of repetitions performed during the series).

Vigour and fatigued

Brunel mood scale (24-item BRUMS) was used to assess vigor and fatigue state on test days (Rohlfs et al. 2008). Participants were instructed to choose from a numerical rating scale of zero to four (0 = not at all, 1 = a bit, 2 = moderate, 3 = enough; 4 = extremely), the option they believe best represents how they felt at that moment (pre-test).

Blood lactate

Blood lactate was measured from a finger prick sample (Portable analyzes - Accusport Boehringer Mannheim – Roche®, Hawthorne, USA) collected immediately after the strength endurance test.

Statistical analyses

All data were presented as mean ± standard deviation and analyzed using the program SigmaPlot version 2012. Normality was checked by the Shapiro-Wilk test. Baseline dietary intake and during placebo or creatine supplementation were compared by one-way analysis of variance (ANOVA). A 2x2 repeated measures analysis of variance was performed (groups: creatine vs placebo) and (time: pre vs post supplementation) to determine differences in the number of repetitions for sets. To test the hypothesis that maximal strength and strength endurance would be greater post-creatine supplementation, a paired t-test or Wilcoxon test was performed. The same tests were performed to evaluate differences between before and after supplementation on blood lactate, RPE, fatigue index, and mood state. We calculated absolute differences within conditions Cr or placebo (i.e. post-pre) of performance variables and compared using an independent t-test or Mann-Whitney test. Effect size (ES) was also calculated using Cohen's standardized differences d with Hedge's adjustment g as per the equation below. An ES of 0.00-0.019 was considered very small; 0.20-0.49 small; 0.50-0.79 moderate; 0.80-1.19 large and 1.20-1.99 very large (Sawilowsky 2009). The significance for all statistical analyses was set at $p \leq 0.05$. g de Hedges = d de Cohen x $\{1- \frac{3}{4}(\eta_1 + \eta_2) - 9\}$.

RESULTS

Performance data

The effects of creatine loading supplementation or placebo on strength endurance training and total work are shown in Figures 2a and b. Only creatine improves strength endurance and total work. The total number of repetitions increases by 14.7% in the creatine group (Pre = 23.8 ± 7.9 reps; Post = 27.3 ± 5.4 reps, p= 0.036, g =0.52) and 1.2% in placebo (Pre = 25.1 ± 6.9 reps; Post

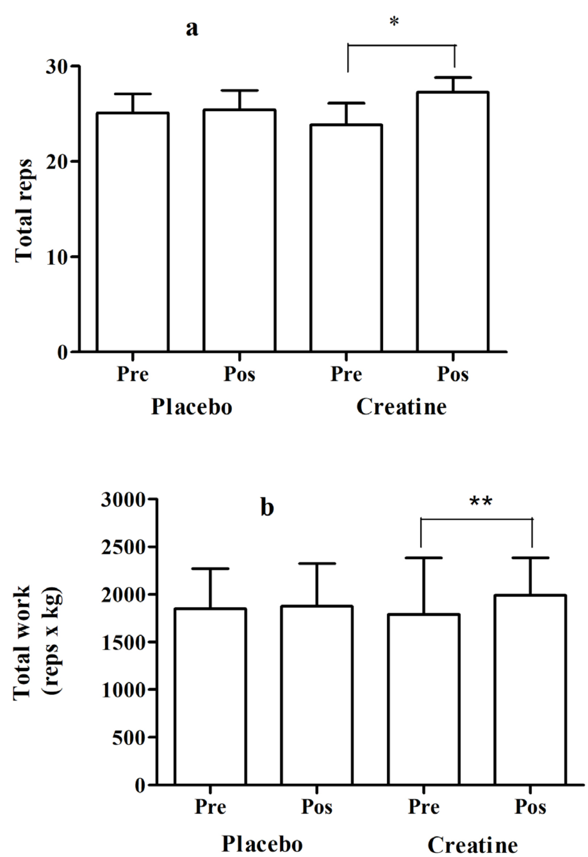

Figure 2. Strength endurance and total work in bench press before and after five days of creatine loading or placebo supplementation. a: strength endurance (total reps= Σ reps/sets), b: total work (reps x sets x kg). *p=0.036, **p=0.038 (one-sided paired *t-test*) pre *vs* post into creatine group. Data are presented as mean ± SD.

= 25.4 ± 7.1 reps, p=0.414, g =0.06). The total work increased 11.1% in creatine (Pre = 1791 ± 592.4; Pos = 1991 ± 395.4, p=0.038, g = 0,52) and only 1.4% no grupo placebo (Pre = 1848 ± 422.9; Pos = 1875 ± 450.1, p=0.402, g = 0,07). We compared the absolute differences (pos minus pre) of strength endurance (Pla= +0,33 vs Cr= +3.4 reps) and total work (Pla=+26.7 vs Cr=+199.5 arbitrary units), and no significant difference was found between placebo and creatine (p<0.05).

The number of repetitions decreased significantly (p<0.001) between the first and the others (2, 3, and 4 sets) bench press sets before (pre) and after (post) creatine or placebo supplementation (Figure 3a, b). There was also a significant reduction in the number of repetitions between the second and fourth sets after creatine supplementation (p=0.049). In the creatine group, the number of repetitions was higher after supplementation in the first (p=0.027) and fourth (p=0.028) sets compared to before supplementation (Figure 3a). No effect of time*sets interation (F=0.492, p=0.689), time*condition (F=3.353, p=0.070), and time*condition*sets (F=1.341, p=0.266).

Five days of creatine loading or placebo no improve 1RM in bench press ([CR, Pre = 106.8 ± 11.7kg; Post = 107.0 ± 11.5kg, Δ=+0.2%, p=0.688]; [PLA, Pre = 107.8 ± 11.7kg; Post = 105.3 ± 10.2kg, Δ= -2.3% p=0.219]) (Figure 4).

Blood lactate and RPE

No effect of creatine supplementation was found on blood lactate (Cr, Pre= 10.0±2.0 mmol.dL^{-1}, Post= 9.8±0.7 mmol.dL^{-1}, p=0.863; PLA, Pre= 10.8±1.9 mmol.dL^{-1}, Post= 10.8±2.3 mmol.dL^{-1}, p=0.984) (Figure 5a). Likewise, RPE remained statistically unaltered after creatine or placebo supplementation (Cr, Pre= 9.6±0.5, Post= 9.3±0.7, p=0.375; Pla, Pre= 9.6±0.5, Post= 9.6±0.7, p=1.00) (Figure 5b).

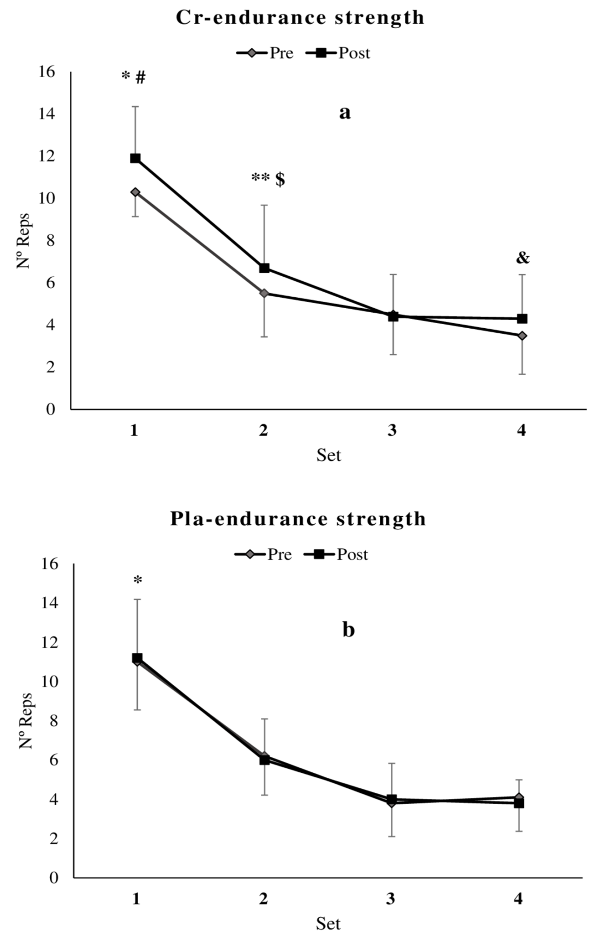

Figure 3. a: number of repetitions pre and post-creatine supplementation, b: number of repetitions pre and post placebo supplementation. *p<0.001 first set is higher than 2,3, and 4 sets before and after supplementation in both groups. **p=0.049 second set is higher than the four set in post-creatine supplementation. #p=0.027(Wilcoxon test), $p=0.081 (One-tailed paired t-test), &p=0.028 (One-tailed paired t-test) the number of reps in the post is higher than pre-creatine supplementation. Data are presented as mean ± SD.

Fatigue index

There was no significant variation in the fatigue index before and after supplementation with placebo or creatine (placebo: pre = 63.0±12.0%, post = 64.3±11.7%, Δ= +2.1%, p=0.784; creatine: pre = 65.7±12.8%, post = 64.7±10.4%, Δ= -1.5%, p=0.780) (Supplementary Material - Figure S1)

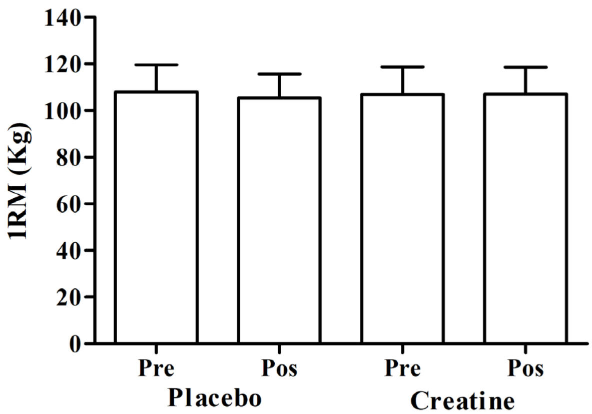

Figure 4. Maximal dynamic strength in the bench press before and after five days of creatine loading or placebo supplementation. Data are presented as mean ± SD.

Vigor and fatigue

Creatine supplementation did not affect the mood state of the participants (Table II). Vigor and fatigue scores remained unaltered after supplementation with creatine or placebo (p>0.05). Similarly, there was no significant difference in the perceived feeling of vigor and fatigue in the creatine or placebo conditions pre and post-supplementation (p>0.05).

Diet

Food intake in baseline, placebo, and creatine were not significantly different for energy (p=0.263), carbohydrate (p=0.167), protein (p=0.466), and fat (0.225).

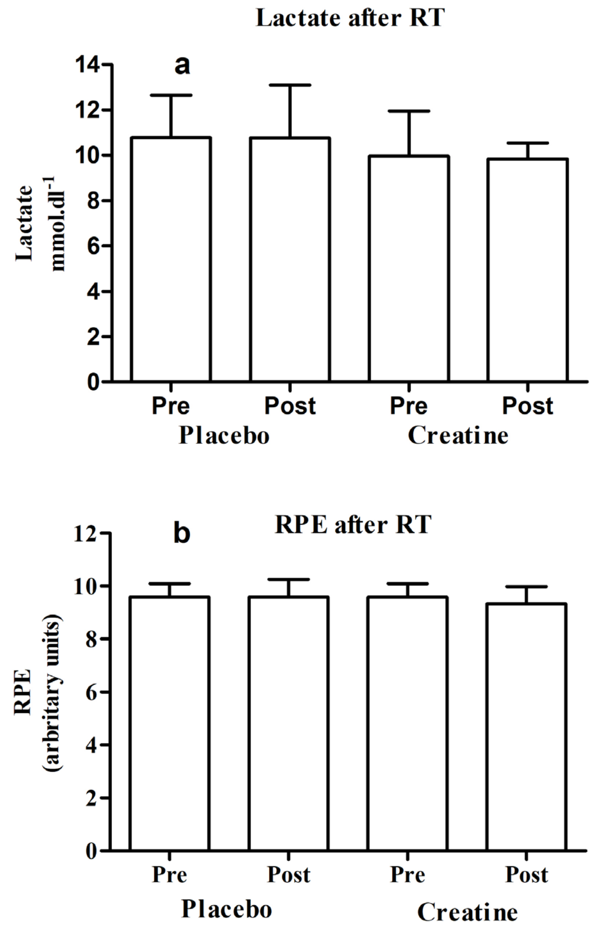

Figure 5. a: blood lactate determined immediately after resistance training (bench press), b: rating of perceived exertion determined immediately after resistance training (bench press). Data are presented as mean ± SD.

DISCUSSION

This study attempts to investigate the effects of creatine loading (20g/d for five days) on maximal dynamic (1RM) and strength endurance (RT) measured in the bench press in a single training session. The main findings of this study were shown that creatine increased significantly the total number of repetitions (+14.7%) and total work (+11.1%) compared to non-treatment. Placebo slightly increased total reps (+1.2%) and total work (+1.4%). Regarding our results, we estimate that the placebo effect represented only 8.6% and 13.4% of the effect observed in true creatine on the total number of repetitions and total work, respectively.

Benefits effects of creatine supplementation on the number of repetitions and total work for bench press exercise were observed in various studies (Volek et al. 1997, Branch 2003, Rawson & Volek 2003). The review of Rawson e Volek (2003) found an increase of 14% higher in creatine supplementation compared to placebo (Cr=+26%, Pla=+12%) in strength endurance during resistance training. The results of the present study corroborate the meta-analysis carried out by Lanhers et al. (2016) who found a positive effect of creatine supplementation on the number of repetitions performed in the bench press exercise in seven out of ten analyzed studies. The authors also reported that creatine was efficient in upper limb strength performance for exercises lasting less than 3 minutes, regardless of the training and supplementation protocols and characteristics of the population.

Short-term creatine supplementation ($20g.d^{-1}$ for five days) can increase stores of Cr and PCr (Preen et al. 2003) and improve performance in high-intensity and intermittent tasks lasting <30 seconds (Hultman et al. 1996, Branch 2003). Possibly the positive effects observed on endurance strength and total work in the present study can be explained by an enhanced ability to resynthesize ATP, faster regeneration of PCr during recovery time between sets, and improved energy supply via anaerobic glycolysis due to its buffering role (Lemon 2002). Thus PCr acts as a temporary energy buffer prolonging the supply of energy in short-duration exercises. In the present study, after creatine supplementation, the exercise duration in the first series (the longest) ranged from 20-28 seconds. The minimum execution time of 4 seconds was observed in a participant in the third series after creatine supplementation. Perhaps, the buffering role of creatine may have played a relevant role in the present study.

Table II. Vigour and fatigue state of participants on test days.

Mood stade	Placebo Mean ± SD	Creatine Mean ± SD
Vigour		
Pre	8.7 ± 4.2	7.9 ± 3.5
Post	8.1 ± 4.3	7.1 ± 4.7
Fatigue		
Pre	3.8 ± 3.2	4.8 ± 4.1
Post	2.7 ± 2.3	4.7 ± 3.9

Data are presented as mean ± SD.

The participants of the present study were trained men engaged in resistance training with a focus on hypertrophy. Creatine supplementation combined with resistance training improves muscle gain more than resistance training alone (Rawson & Persky 2007). The bench press used in the present study is common in resistance training programs typically performed 8-12 repetitions to 60-80% of 1RM (ACSM 2009). However, in bodybuilding gyms, the training load is rarely chosen based on the 1RM test. The increase in the training volume (N° of reps) and total work (reps x kg) are important drivers to hypertrophy (Schoenfeld et al. 2021). Thus, our results suggest that when subjects engaged in resistance training take creatine supplementation, they actually can improve their strength endurance performance and gain muscle mass. Beyond creatine supplementation, subjects who want to gain muscle mass should know that muscle hypertrophy is affected by some factors such as muscle variables (volume, intensity, rest interval, etc.) and dietary (energy and proteína intake mainly) (Stokes et al. 2018).

In contrast, when assessing maximal dynamic strength (1RM), creatine supplementation did not significantly alter performance (Fig. 2a). Several studies have not detected positive effects of creatine supplementation on maximal strength compared to placebo (Law et al. 2009, Zuniga et al. 2012, Feuerbacher et al. 2021), while other studies have observed increased performance (Rawson & Volek 2003, Cooper et al. 2012, Wang et al. 2018, Lanhers et al. 2016). It has been observed that trained subjects, such as the participants in the present study, tend to have a lesser effect on maximal strength with creatine supplementation (Branch 2003, Rawson & Volek 2003, Lanhers et al. 2016). MacDougall et al. (1977) reported that only five months of heavy resistance training can increase resting muscle PCr by 22%. The subjects in the present study had 5.9 ± 3.1 years of experience with resistance training, which may predispose these subjects to have higher resting muscle creatine levels and thus show less effect of creatine supplementation. Finally, the effects of creatine on maximal strength tend to be smaller than on endurance strength and total work (Branch 2003, Cooper et al. 2012).

The traditional protocol for the development of maximum strength consists of training with high loads (≥ 100% of 1RM) and few movements (≤ 3 repetitions), being very specific to the objective (ACSM 2009, Haff & Triplett 2015). The subjects in the present study, even though they are adapted to weight training, routinely perform a higher volume (sets x repetitions) with moderate loads in training sessions, thus they may not have the necessary adaptations to increase maximal strength during the short supplementation period of and creatine per se was not able to induce an increase in maximal strength. This seems to demonstrate that increasing muscle concentrations of this compound without having the specific mechanical stress (specificity) did not lead to significant changes in muscle function.

In the present study, the blood lactate measured immediately after resistance training remained unaltered by creatine supplementation. This result disagrees with that of Volek et al. (1997), who observed a significant difference in blood lactate levels after creatine supplementation (pre = 9.8 ± 2.0 and post 11.3 ±1.8 mmol.L^{-1}) after 5 series to failure in the bench press. Although the subjects in this study performed about 4 more repetitions after creatine supplementation, there was no increase in lactate, which may be associated with the possible inhibition of phosphofructokinase by phosphocreatine that would reduce the rate of glycolysis and lactate production (Storey & Hochachka 1974). Other studies have also observed no changes in blood lactate post-exercise with creatine supplementation (Dawson et al. 1995, Peyrebrune et al. 1998, Aedma et al. 2015) and others have demonstrated a significant reduction in lactate (Balsom et al. 1993, Oliver et al. 2013).

Despite the improved performance in resistance training found in the present study, creatine supplementation did not improve RPE and fatigue index compared to placebo. The average RPE values reported by the participants were high (>9 on a maximum scale of 10), indicating the high intensity of the training session. The PSE evaluated post-exercise may better reflect the perception of effort at the end of the exercise rather than the stress of the exercise itself (Duncan & Oxford 2011). These results are in line with the findings of Lee et al. (2011) and Paiva et al. (2020), who did not find changes in PSE after creatine loading. Similar to the results observed in the present study, Paiva et al. (2020) found an increase in the number of repetitions in the bench press without alteration of RPE. Regarding the fatigue index, the results observed in the present study were different from those found by Ateş et al. (2017) (using the Rast test) and Sampaio et al. (2020) (using an isometric bench press), who found a reduction in FI with creatine loading. The fatigue index tends to be more affected when the bench press is performed after pre-exhaustion with another exercise (e.g., triceps), which was not done in the present study (Ribeiro et al. 2014). These results suggest that a greater training stimulus can be achieved with similar perceived exertion and fatigue index after five days of creatine loading.

Mood state can affect performance. The combination of low fatigue scores with high vigor scores is associated with a positive mental attitude and better physical performance (Terry et al. 2003, Brandt et al. 2016, Brandão et al. 2021). In the present study, no changes were observed in the mood state for vigor and fatigue subscales of the BRUNS after creatine loading or placebo. Thus, the effect of creatine on strength endurance found in the present study cannot be attributed to a change in mood state.

Among the limitations of this study, we could mention that: (a) Muscle creatine levels were not evaluated by biopsies before and after the supplementation period. Thus, we could not determine the magnitude of the increase in muscle creatine. (b) We only evaluated the effects of short-term creatine loading on acute exercise performance. Furthermore, we only used the bench press exercise to evaluate performance, which is not fully representative of an athlete's training session that commonly involves multiple exercises. Future long-term supplementation and training studies are required to confirm these results. (c) another possible limitation was the small sample size used, however, the number of participants in the present study is comparable to those used in previous studies (Syrotuik & Bell 2004, Feuerbacher et al. 2021). (d) Finally, we only evaluated male participants, and future investigations should include women.

CONCLUSIONS

Supplementation with high doses of creatine (20 g/day) for five days allowed the subjects to perform more repetitions until reaching concentric failure, resulting in a greater training volume, which together with other factors predisposes the body to develop muscle hypertrophy. However, this supplementation protocol could not alter the participants' maximum strength, blood lactate, RPE, fatigue index, and mood state.

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SUPPLEMENTARY MATERIAL

Figure S1.

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