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Clayton L. Camic
University of Wisconsin-La Crosse, ccamic@uwlax.edu

Terry J. Housh
University of Nebraska-Lincoln, thoush1@unl.edu

Jorge M Zuniga
Creighton University, jorgezuniga@creighton.edu

Daniel A. Traylor
University of Nebraska-Lincoln

Haley Bergstrom
University of Nebraska-Lincoln, hbergstrom@uky.edu

See next page for additional authors

Authors

Clayton L. Camic, Terry J. Housh, Jorge M Zuniga, Daniel A. Traylor, Haley Bergstrom, Richard J. Schmidt, Glen O. Johnson, and Dona J. Housh

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The Effects of Polyethylene Glycosylated Creatine Supplementation on Anaerobic Performance Measures and Body Composition

Clayton L. Camic,[1] Terry J. Housh,[2] Jorge M. Zuniga,[3] Daniel A. Traylor,[2] Haley C. Bergstrom,[2] Richard J. Schmidt,[2] Glen O. Johnson,[2] and Dona J. Housh[4]

1 Department of Exercise and Sport Science, Human Performance Laboratory, University of Wisconsin-La Crosse, La Crosse, Wisconsin
2 Department of Nutrition and Health Sciences, University of Nebraska-Lincoln, Lincoln, Nebraska
3 Department of Exercise Science, Creighton University, Omaha, Nebraska
4 Department of Oral Biology, University of Nebraska Medical Center, Lincoln, Nebraska

Corresponding author – Clayton L. Camic, email ccamic@uwlax.edu

Abstract

The purpose of this study was to examine the effects of 28 days of polyethylene glycosylated creatine (PEG-creatine) supplementation (1.25 and 2.50 g · d^{-1}) on anaerobic performance measures (vertical and broad jumps, 40-yard dash, 20-yard shuttle run, and 3-cone drill), upper- and lower-body muscular strength and endurance (bench press and leg extension), and body composition. This study used a randomized, double-blind, placebo controlled parallel design. Seventy-seven adult men (mean age ± SD, 22.1 6 2.5 years; body mass, 81.7 ± 10.8 kg) volunteered to participate and were randomly assigned to a placebo (n = 23), 1.25 g · d^{-1} of PEG-creatine (n = 27), or 2.50 g · d^{-1} of PEG-creatine (n = 27) group. The subjects performed anaerobic performance measures, muscular strength (one-repetition maximum [1RM]), and endurance (80% 1RM) tests for bench press and leg extension, and underwater weighing for the determination of body composition at day 0 (baseline), day 14, and day 28. The results indicated that there were improvements (p , 0.0167) in vertical jump, 20-yard shuttle run, 3-cone drill, muscular endurance for bench press, and body mass for at least one of the PEG-creatine groups without changes for the placebo group. Thus, the present results demonstrated that PEG-creatine supplementation at 1.25 or 2.50 g · d^{-1} had an ergogenic effect on lower-body vertical power, agility, change-of-direction ability, upper-body muscular endurance, and body mass.

Keywords: PEG, supplements, strength, endurance

Introduction

Previous investigations have shown that creatine supplementation provides an ergogenic effect for various measures of anaerobic exercise performance. In particular, it has been demonstrated that short-term loading (20–25 g · d-1, 5–7 days) or long-term chronic doses (3 g· d^{-1}, ≥30 days) of creatine monohydrate (CM) can lead to improvements in one-repetition maximum (1RM) strength, muscular endurance, anaerobic power, speed, and sprinting performance (5,15,17,19,22,24,25,32–34,36). Traditionally, the methods used to assess these variables include dynamic constant external resistance exercises (i.e., free weights, weight machines) and anaerobic performance measures such as the Wingate test (5,15,19). In addition, the majority of these studies (5,15,17,19,22,24,25,32–34,36) have included resistance training during the supplementation period and have used cycle ergometry, not running, to assess sprinting performance. There are limited data, however, regarding the influence of creatine supplementation on standardized field assessments of power, lateral speed, agility, and change-of-direction ability that are commonly used to predict athletic performance. Based on the short-duration high-intensity nature of frequently used tests such as the broad and vertical jumps, 40-yard dash, 20-yard shuttle run, and 3-cone drill, it is likely that supplementation with creatine would serve as an effective ergogenic aid for these activities. For example, the physiological benefits of creatine supplementation have been attributed to enhanced adenosine triphosphate (ATP) regeneration, shortened muscle relaxation time, improved efficiency of cross-bridge cycling (35), and body composition (17,22,28,36). Therefore, it is possible that these adaptations would facilitate the maximal, and often repetitive, muscular contractions associated with standardized field assessments (i.e., broad and vertical jumps, 40-yard dash, 20- yard shuttle run, 3-cone drill), thereby improving performance in these areas.

Polyethylene glycol (PEG) is a nontoxic water-soluble polymer that is commonly bound to various substances and functions as a delivery system to enhance the absorption of medications (3), vitamins (23), and nutritional supplements including creatine (5,12,19) and L-arginine (6,7). When attached to PEG, creatine has been shown to have greater uptake efficiency (12) and provide ergogenic effects with smaller supplementation doses compared with CM (19). Specifically, Herda et al. (19) established that supplementation with 1.25 and 2.50 g· d^{-1} of PEG-creatine for 30 days without concurrent resistance training improved measures of upper- and lower-body strength to the same extent as 5 g · d^{-1} of CM. It is possible that these findings (19) were attributable, in part, to changes in body composition leading to greater muscular strength. In particular, recent investigations have shown that supplementation with creatine may promote favorable effects on fat-free mass (FFM) by stimulating protein synthesis (36) and inhibiting protein catabolism (28). Thus, in addition to the ergogenic effects related to enhanced ATP regeneration and subsequent ability to maintain high-intensity exercise, PEG-creatine supplementation may provide improvements in body composition that are not associated with those of resistance training. Based on these mechanisms, it is possible that supplementation with PEG-creatine would improve the short-duration, high-intensity standardized field assessments of anaerobic performance. Therefore, the purpose of this study was to examine the effects of 28 days of PEG-creatine supplementation (1.25 and 2.50 g· d^{-1}) on anaerobic performance measures (vertical and broad jumps, 40-yard dash, 20-yard shuttle run, and 3-cone drill), upper- and lower-body muscular strength and endurance (bench press and leg extension), and body composition.

Methods

Experimental Approach to the Problem

This study used a randomized, double-blind, placebo controlled parallel design. During the first laboratory visit, each subject performed anaerobic performance measures including vertical jump, broad jump, 40-yard dash, 20-yard shuttle run, and 3-cone drill that have commonly been used at the National Football League Scouting Combine. Procedures used for these anaerobic performance measures were consistent with those previously reported (26,29,30). After 24 hours, each subject returned to the laboratory to complete the second visit (day 0) that involved assessment of muscular strength (1RM) and endurance (maximal number of repetitions completed at 80% 1RM) for the bench press and bilateral leg extension exercises. In addition, during the second laboratory visit, each subject performed underwater weighing for the determination of body composition and was randomly assigned to one of 3 groups: (a) placebo (n = 23); (b) 1.25 g · d^{-1} of PEG-creatine (PEG1.25; n = 27); or (c) 2.50 g · d^{-1} of PEG-creatine (PEG2.50; n = 27). The ingredients for the supplement included 1.25 g or 2.50 g of PEG-creatine, whereas the placebo consisted of microcrystalline cellulose. The subjects were asked to ingest 1 dose (4 tablets) every day with approximately 0.5 L of water for 28 days. After 2 weeks of supplementation (day 14), the subjects returned to the laboratory for visits 3 and 4 (separated by 24 hours) to perform the anaerobic performance measures, muscular strength and endurance exercises, and underwater weighing using the same protocol as during the baseline measurements. After 2 additional weeks of supplementation (day 28), the testing procedures were repeated during the fifth and sixth laboratory visits (separated by 24 hours). During the course of the study, the subjects were encouraged to continue with their normal exercise and dietary habits. Subjects were also instructed to refrain from exercise for 48 hours before each laboratory visit. Furthermore, each subject completed a 3-day food log during the first and last week of the supplementation period to ensure there were no significant changes in total caloric (kcal), protein, carbohydrate, and fat intake.

Subjects

Seventy-seven adult men (mean age ± SD, 22.1 ± 2.5 years; body mass, 81.7 ± 8.4 kg; height, 181.7 ± 5.3 cm) volunteered to participate in this investigation. The subjects were untrained in resistance exercise and engaged in no more than 4 hours of recreational activity per week. All of the subjects were University of Nebraska undergraduate or graduate students. Data collection was performed during the fall semester. In addition, the subjects did not report or exhibit any of the following that could have significantly affected the outcome of the study: (a) a history of medical or surgical events, including cardiovascular disease, metabolic, renal, hepatic, or musculoskeletal disorders; (b) use of any medication; (c) use of nutritional supplements; or (d) participation in another clinical trial or ingestion of another investigational product within thirty days before screening/ enrollment. The study was approved by the University Institutional Review Board for Human Subjects, and all participants completed a health history questionnaire and signed a written informed consent document before the testing.

Procedures

Vertical Jump. Vertical jump height was measured using the Vertec vertical jump device (Gill Athletics, Champaign, IL, USA). Each subject was positioned directly underneath the Vertec and instructed to jump as high as possible from a standing 2-foot position and move the highest horizontal vane with a single hand (29). Each subject performed 3 vertical jumps with 2 minutes of rest between each trial. Vertical jump height was calculated as the difference between the highest vane of the Vertec reached and the standing reach height.

Broad Jump.
The standing broad jump test involved each subject standing in a 2-foot position with their toes directly behind the starting line and jumping forward for maximal horizontal distance. The standing broad jump distance was measured as the farthest horizontal distance reached by the landing contact point of the heel from the starting line (29). Each subject performed 3 standing broad jump trials with 2 minutes of rest between each trial.

40-Yard Dash.
The 40-yard dash involved measuring the time (hand timed by the same investigator) required to sprint 40 yards as fast as possible. Each subject was positioned in a 3- point stance behind the starting line and was instructed to sprint the distance of 40 yards as fast as possible. Two cones were used to represent the starting line, and 2 cones were placed 40 yards down field to represent the finishing line that each subject was instructed to run through. Subjects performed two 40-yard dash time trials separated by 2 minutes with the fastest time used as the representative 40-yard dash time.

20-Yard Shuttle Run.
The shuttle run involved each subject completing 20 total yards of lateral movement with 2 changes in direction in the fastest time possible. The starting position involved each subject straddling the middle of 3 parallel lines spaced 5 yards apart from one another. From the starting (middle) line, the subject ran 5 yards to the right, touched the farthest right line with their right hand, quickly changed direction, and ran 10 yards back to the left passing the starting line. After reaching down and touching the far left line with their left hand, the subject again changed direction and sprinted 5 yards to the right passing the starting line (29). Each subject performed 2 trials separated by 2 minutes of rest. The shuttle run time was recorded as the fastest time required to complete the 20-yard course.

3-Cone Drill.
The 3-cone drill involved each subject running a specific route around 3 cones placed 5 yards apart in an “L” formation (30). Each subject performed 2 trials separated by 2 minutes of rest. The fastest time required to complete the course was used as the representative 3-cone drill time.

Muscular Strength and Endurance.
The 1RM dynamic constant external resistance (DCER) muscular strength was determined for the leg extension ($1RM_{LE}$) and bench press ($1RM_{BP}$) exercises. The leg extension exercises were performed on a plate-loaded leg extension resistance training machine (Body-Solid, Forest Park, IL, USA). Each subject sat with their back flat against the backrest and was instructed to hold tightly to the handles of the device. The backrest was adjusted to align the anatomical axes of the knee with the mechanical axis of the machine. The subject’s legs were placed against shin pads that were attached to the lever arm of the machine. The distance between the shin pads and the axis of rotation of the lever arm was fixed and not adjustable. The positioning of each subject, however, was consistent across all tests. The bench press exercises were performed on a standard free-weight bench (Body Power, Williamsburg, VA, USA) with an Olympic bar. After receiving a lift-off from a spotter, the subject lowered the bar to their chest, paused briefly, and then pressed the bar to full extension of the forearms. For both the leg extension and bench press exercises, 1RM DCER strength was determined by applying progressively heavier loads until the subject could not complete a repetition through the full range of motion. Additional trials were performed with lighter loads until the 1RM was determined within 2.27 kg, and this was typically achieved within 5 trials. Two minutes of rest were allowed between all trials. For the leg extension (REP_{LE}) and bench press (REP_{BP}) endurance testing, subjects performed as many repetitions as possible of full extension of the legs and forearms at 80% of their baseline (day 0) 1RM. During day 0, day 14, and day 28, the same procedures for leg extension and bench press testing were performed. The test-retest reliability data from our laboratory for leg extension and bench press strength testing indicated that for adult male subjects ($n = 20$) measured 8 weeks apart, the intraclass correlations (ICC) were 0.98 and 0.99, respectively, with no significant ($p > 0.05$) mean differences between test and retest values.

Underwater Weighing.
Body density was assessed from underwater weighing (UWW), with correction for residual lung volume (RV) using the oxygen dilution method of Wilmore (38). Residual lung volume was determined with the subject seated in a position similar to that assumed during UWW. The average of similar scores (within 100 mL) from 2 to 3 trials was used as the representative RV. Underwater weight was measured in a hydrostatic weighing tank in which a nylon swing seat was suspended from a 10-kg Salter scale (REGO Designs & Patents, model 230). The average of the 3 highest values from 6 to 10 trials was used as the representative underwater weight. Percent body fat (% fat) was calculated using the formula of Brozek et al. (4), with fat mass and FFM derived mathematically. Previous test retest reliability data for UWW from our laboratory for % fat indicated that for young adult male subjects ($n = 16$) measured 24–72 hours apart, the ICC was 0.98, with a standard error of measurement of 0.9% fat and no significant ($p > 0.05$) mean differences between test and retest values.

Statistical Analyses
Vertical jump, broad jump, 40-yard dash, 20-yard shuttle run, and 3-cone drill times as well as $1RM_{BP}$, $1RM_{LE}$, REP_{BP}, REP_{LE}, body mass, % fat, fat mass, FFM, were analyzed with separate 3 X 3 mixed factorial analysis of variance (ANOVAs) (time [day 0, day 14, day 28] X group [placebo, 1.25 g $\cdot$ d^{-1}, 2.50 g$\cdot$ d^{-1}]). In addition, 1-way follow-up repeated measures ANOVAs across time for a priori planned comparisons by group were conducted and post

Table 1. Physical characteristics and performance measures at day 0, 14, and 28 for the placebo, 1.25 g· d^{-1} polyethylene glycosylated creatine ($PEG_{1.25}$),and 2.50 g· d^{-1} polyethylene glycosylated creatine ($PEG_{2.50}$) groups.

	Placebo (n = 23)			$PEG_{1.25}$ (n = 27)			$PEG_{2.50}$ (n = 27)		
	Day 0	Day 14	Day 28	Day 0	Day 14	Day 28	Day 0	Day 14	Day 28
Vertical jump (cm)	58.9 (1.8)	60.0 (1.9)	60.7 (1.8)	63.0 (1.5)	65.5 (1.4)*	65.8 (1.4)*	58.7 (1.8)	59.7 (1.9)	61.0 (2.0)*
Broad jump (cm)	228.2 (3.9)	232.6 (4.3)*	234.1 (3.8)*	236.0 (3.5)	238.0 (3.2)	241.9 (3.2)*	229.6 (5.7)	229.9 (4.5)	237.3 (4.9)*†
40-yard dash (s)	5.53 (0.07)	5.33 (0.06)*	5.27 (0.06)*	5.43 (0.06)	5.24 (0.05)*	5.13 (0.06)*†	5.60 (0.08)	5.40 (0.06)*	5.23 (0.06)*†
Shuttle run (s)	5.27 (0.21)	4.92 (0.05)	4.88 (0.05)	5.04 (0.05)	5.03 (0.05)	4.83 (0.04)*†	5.08 (0.06)	4.97 (0.04)*	4.86 (0.05)*†
3-cone drill (s)	8.14 (0.22)	8.23 (0.09)	8.23 (0.07)	8.44 (0.08)	8.30 (0.08)	8.29 (0.08)	8.55 (0.09)	8.31 (0.07)*	8.31 (0.08)*
Bench press 1RM (kg)	87.0 (4.1)	88.4 (4.1)*	89.2 (4.1)*	89.3 (4.0)	91.9 (4.1)*	93.1 (4.0)*	88.5 (4.0)	91.0 (3.7)*	92.8 (3.7)*†
Bench press endurance (repetitions to failure)	8.0 (0.4)	8.5 (0.3)	8.9 (0.4)	7.4 (0.6)	8.6 (0.4)	9.3 (0.5)*	8.7 (0.5)	9.1 (0.6)	10.6 (0.6)*†
Leg extension 1RM (kg)	96.0 (5.2)	109.8 (5.5)*	112.0 (4.8)*	104.0 (3.4)	115.1 (4.3)*	121.5 (4.6)*	100.0 (4.8)	111.4 (4.7)*	113.8 (4.7)*
Leg extension endurance (repetitions to failure)	13.2 (0.9)	17.0 (1.4)	18.6 (1.8)*	12.8 (0.8)	16.8 (1.4)*	19.7 (1.6)*†	12.8 (1.0)	16.9 (1.5)*	18.3 (1.6)*
Body mass (kg)	80.2 (2.3)	80.5 (2.3)	80.5 (2.4) 7	9.8 (2.0)	80.2 (2.0)	80.7 (2.0)*	81.3 (2.1)	82.2 (2.1)*	82.7 (2.1)*†
Body fat (%)	16.2 (1.2)	16.1 (1.1)	15.7 (1.0)	14.6 (1.2)	14.5 (1.1)	14.1 (1.1)	16.3 (1.3)	16.2 (1.2)	16.2 (1.3)
Fat mass (kg)	13.5 (1.4)	13.4 (1.3)	13.0 (1.2)	12.0 (1.2)	12.0 (1.1)	11.7 (1.1)	13.6 (1.3)	13.6 (1.2)	13.7 (1.3)
Fat-free mass (kg)	66.7 (1.2)	67.1 (1.2)	67.5 (1.3)*	67.8 (1.4)	68.2 (1.4)	69.0 (1.4)*†	67.7 (1.5)	68.6 (1.5)*	69.0 (1.5)*

1RM = 1 repetition maximum.

Values are expressed as mean (SE).

* Significantly ($P < 0.0167$) different from day 0.

† Significantly different from day 14.

hoc analyses included paired sample t-tests with Bonferroni corrections (0.05/3 = 0.0167). An alpha of $p < 0.05$ was considered statistically significant for all interaction effects and follow-up ANOVAs. In addition, the total caloric (kilocalories) and macronutrient (grams of protein, carbohydrate, and fat) intake were analyzed with separate 2 (time [day 0, day 28]) X 3 (group [1.25 g · d^{-1}, 2.50 g · d^{-1}, placebo]) mixed factorial ANOVAs.

Results

The results of the statistical analyses for the performance measures at day 0, 14, and 28 for the placebo, $PEG_{1.25}$, and $PEG_{2.50}$ groups are provided in Table 1. The findings indicated that there were significant increases in vertical jump ($PEG_{1.25}$ and $PEG_{2.50}$), REPBP ($PEG_{1.25}$ and $PEG_{2.50}$), and body mass ($PEG_{1.25}$ and $PEG_{2.50}$), without changes for the placebo group. There were also significant decreases in the 20-yard shuttle run ($PEG_{1.25}$ and $PEG_{2.50}$) and 3-cone drill ($PEG_{2.50}$), without changes for the placebo group. For broad jump, 40-yard dash, $1RM_{BP}$, $1RM_{LE}$, REP_{LE}, and FFM, however, there were changes for all 3 groups (placebo, $PEG_{1.25}$, and $PEG_{2.50}$). There were no changes in % fat, fat mass, total calories, or macronutrients consumed for any of the groups.

Discussion

The findings of the present investigation indicated that supplementation with 1.25 or 2.50 g · d^{-1} of PEG-creatine led to significant improvements in vertical jump, 20-yard shuttle run, 3-cone drill, REPBP, and body mass (Table 1). For broad jump, 40-yard dash, 1RMBP, 1RMLE, REPLE, and FFM, however, there were no significant differences among both PEG-creatine groups (1.25 and 2.50 g· d21) and the placebo group. Thus, the results of this study demonstrated that PEG-creatine supplementation had an ergogenic effect on lower-body vertical power, upper-body muscular endurance, agility, change-of-direction ability, and body mass, but not on speed, upper-body muscular strength, lower-body horizontal power, muscular strength, or endurance.

In general, previous studies (21,27) have shown that short-term creatine supplementation without resistance training had no influence on vertical jump performance. For example, Izquierdo et al. (21) found that 5 days of loading (20 g · d^{-1}) with CM did not improve vertical jump height in a sample of male handball players (n = 19). Mujika et al. (27) also determined that 6 days of CM loading (20 g · d^{-1}) resulted in no change in vertical jump (47.4 6 6.0 cm to 46.8 6 6.0 cm) in male soccer athletes (n = 17). It has been suggested (27) that short-term creatine loading may not be beneficial for performances related to overcoming gravity such as vertical jump, because of the associated increase in body mass caused by water retention. Furthermore, because of the short duration (i.e., ,1 second) in performing a vertical jump, it is likely that phosphocreatine stores are not the limiting factor for this activity, and therefore, may not be influenced by CM loading (25). In combination with resistance training, how ever, longer-term supplementation with creatine may lead to improvements in vertical jump as the result of increased FFM (27,32). This suggestion is supported by the findings of Haff et al. (17) and Kirksey et al. (22) that demonstrated concurrent increases in vertical jump performance and FFM after 6 weeks of creatine supplementation (0.3 g · kg^{-1} · d^{-1}) and resistance training in track and field athletes. In this investigation, there were significant increases in vertical jump after 28 days of supplementation for the $PEG_{1.25}$ (63.0 ± 1.5 cm to 65.8 ± 1.4 cm) and $PEG_{2.50}$ (58.7 ± 1.8 cm to 61.0 ± 2.0 cm) groups, but no change (58.9 ± 1.8 cm to 60.7 ± 1.8 cm) in the placebo group. Therefore, although we did not use a concurrent resistance training program, it is possible that the changes in vertical jump for the PEGcreatine groups were related to the increased FFM ($PEG_{1.25}$: 67.8 ± 1.4 kg to 69.0 ± 1.4 kg; $PEG_{2.50}$: 67.7 ± 1.5 kg to 69.0 ± 1.5 kg) from day 0 to day 28. In contrast, however, the placebo group also exhibited increased FFM (66.7 ± 1.2 kg to 67.5 ± 1.3 kg) over the same time period, but experienced no improvement in vertical jump. It is possible that these findings were related to the amount of absolute change in FFM among the PEG1.25 (+1.2 kg), PEG2.50 (+1.3 kg), and placebo groups (+0.8 kg). The present results also indicated that there were no improvements in broad jump performance at day 14 or day 28 for the $PEG_{1.25}$ or $PEG_{2.50}$ groups when compared with the placebo group. Both vertical jump and broad jump have been described as measures of lower-body power and have been shown to be moderately correlated (r = 0.74) (29). Based on these findings (29), we hypothesized that the creatine-induced changes in performance would be similar between vertical jump and broad jump. The mechanism responsible for the discrepancy in the results remains uncertain, but may have been because of the relatively smaller doses of PEG-creatine (1.25 and 2.50 · g d^{-1}) used in this study compared with previous investigations (22,24,25,34,36) that have used large loading doses of CM and shown improvements in lower body power. Future studies should further examine the effects of PEG-creatine on vertical and broad jump performance using larger doses or longer supplementation periods.

The results of this investigation indicated there were significant decreases in 40-yard dash time from day 0 to day 28 for the $PEG_{1.25}$ (5.43 ± 0.06 seconds to 5.13 ± 0.06 seconds) and $PEG_{2.50}$ (5.60 ± 0.08 seconds to 5.23 ± 0.06 seconds) groups as well as the placebo group (5.53 ± 0.07 seconds to 5.27 ± 0.06 seconds). In general, the findings of previous studies (11,14,32) have suggested that the ergogenic effect of creatine supplementation on sprinting performance may vary based on differences in training status, athletic sample examined, sprint distance assessed, or addition of a concurrent resistance training program. For example, Glaister et al. (14) found no improvements for 30-meter dash time after 5 days of loading with CM (20 g · d^{-1}) in a sample (n = 21) of college-aged men who regularly participated in multiple sprint activities. Delecluse et al. (11) also reported no change in 40-meter dash performance (5.09 ± 0.09 seconds to 5.08 ± 0.10 seconds) after 7 days of loading (0.35 g · kg^{-1} · d^{-1}) with CM in elite college sprinters (n = 7). The authors (11) contented that the mechanisms underlying the benefits of creatine supplementation may already be optimized in highly trained sprinters because of multiple years of intensive sprint training. This suggestion (11), however, is not consistent with the findings of Skare et al. (31) that indicated 20 g · d^{-1} of CM for 5 days decreased 60-m and 100-m (11.68 ± 0.27 seconds to 11.59 ± 0.31 seconds) times in a sample of sprinters (n = 9) during a concurrent resistance training program. Stout et al. (32) also found improvements in 100-yard dash time (12.13 ± 0.36 seconds to 11.82 ± 0.37 seconds) after 8 weeks of supplementation with CM (21 g · d^{-1} for 5 days, 10.5 g · d^{-1} thereafter) in resistance-trained college football players. It has been demonstrated that creatine supplementation with resistance training provides greater improvements in performance compared with just creatine supplementation or resistance training alone (1). These findings (1) offer a plausible explanation for the ergogenic effects observed after supplementation with CM in the resistance-trained athletes of Stout et al. (32) and Skare et al. (31) compared with the lack of improvement in the participants of this investigation and previous studies (11,14) who were not engaged in a concurrent resistance training program during the course of the study. In conjunction, the present findings and those of others (11,14,31,32) suggested that creatine supplementation may improve 40- and 100-yard dash performance only when combined with resistance-training.

To the best of our knowledge, no previous investigations have examined the effects of creatine supplementation on the 20-yard shuttle run and 3-cone drill, which have been described as performance measures related to anaerobic power, speed, change-of-direction ability, and agility (26,29). Our results demonstrated there were significant decreases in shuttle run times for the $PEG_{1.25}$ group from day 0 (5.04 ± 0.05 seconds) and day 14 (5.03 ± 0.05 seconds) to day 28 (4.83 ± 0.04 seconds); and $PEG_{2.50}$ group from day 0 (5.08 ± 0.06 seconds) to day 14 (4.97 ± 0.04 seconds) day 28 (4.86 ± 0.05 seconds). In addition, there were significant decreases in 3-cone drill time for the $PEG_{2.50}$ group from day 0 (8.55 ± 0.09 seconds) to day 14 (8.31 ± 0.07 seconds) and day 28 (8.31 ± 0.08 seconds), but not the $PEG_{1.25}$ or placebo groups. The physiological mechanisms that were responsible for faster 20-yard shuttle run and 3-cone drill performances may be related to the shortened muscle relaxation time associated with CM supplementation (35). Specifically, the findings of van Leemputte et al. (35) suggested that greater intracellular stores of phosphocreatine would lead to improved efficiency of sarcoplasmic Ca++-ATPase activity and cross-bridge cycling, thereby decreasing the energy costs of human skeletal muscle relaxation. It is possible that these adaptations would contribute to increased power production by skeletal muscle and enable maximal, high-intensity muscular contractions to continue for a greater period of time (35). In theory, the proposed mechanisms would facilitate the rapid and repeated muscle actions required during the 20-yard shuttle run and 3-cone drill, leading to enhanced performance in these activities. Future studies should further examine the effects of creatine supplementation on physical measures involving multiple high-intensity muscular contractions associated with change-of-direction ability and agility. The findings of this study, however, indicated that supplementation with 2.50 g · d^{-1} of PEG-creatine provided an ergogenic effect for the 20-yard shuttle run and 3-cone drill.

Recent investigations (13,34,39) have reported conflicting results regarding the effect of creatine supplementation without concurrent resistance training on muscular strength. For example, it has been demonstrated that 25 g · d^{-1} of CM for 5 days increased concentric, isokinetic peak torque of the leg extensors at 1808 · s^{-1}(34), but 20 g · d^{-1} over the same time period resulted in no change (13). In addition, loading doses of 20 g · d^{-1} for 5 days have been shown to increase 1RM half-squat, but not $1RM_{BP}$ (21). Zuniga et al. (39) also examined loading doses of 20 g · d^{-1} of CM and found no improvements in $1RM_{LE}$ or $1RM_{BP}$ after 7 days of supplementation. Other studies (5,19) involving non-loading chronic doses of PEG-creatine (1.25–5.00 g · d^{-1}) and the assessment of muscular strength have also provided inconsistent results, particularly between upper- and lower-body 1RM measures. Specifically, 4 weeks of supplementation with 1.25, 2.50, and 5.00 g · d^{-1} of PEG-creatine has been shown to improve 1RMBP (5,19). For measures of lower body strength, however, these investigations found that 1.25 and 2.50 g · d^{-1} increased 1RM leg press (19), but 5.0 g · d^{-1} had no effect on 1RMLE (5). In this investigation, there were increases in both $1RM_{BP}$ and $1RM_{LE}$ from day 0 to day 28 for the $PEG_{1.25}$, $PEG_{2.50}$, and placebo groups. Collectively, the present findings and those of others (5,13,19,21,34,39) indicated that chronic doses (1.25–5.0 g · d^{-1}) of PEG-creatine and loading doses of CM up to 20 g · d^{-1} may not improve lower-body strength when assessed with the leg extension exercise. Furthermore, in contrast to Herda et al. (19), the results of this investigation also demonstrated that supplementation with 1.25 and 2.50 g · d^{-1} of PEG-creatine, like loading doses of CM (20 g · d^{-1}) (21,39), may not increase upper-body muscular strength without resistance training.

Creatine supplementation largely benefits exercise performance through enhanced levels of phosphocreatine within the muscle that facilitate the regeneration of ATP from ADP by means of creatine kinase. Therefore, this mechanism would primarily be useful during repeated bouts of high intensity activity and enable larger volumes of work to be accomplished during resistance training with subsequent increases in muscular strength and endurance. Previous studies have shown that typical loading periods (20 g · d^{-1} for 5–7 days) (18) and smaller chronic doses (3 g · d^{-1} for 28 days) (20) of CM can elevate intramuscular phosphocreatine and total creatine stores to ergogenic levels. In addition, Fry et al. (12) demonstrated through biopsies that 10 g · d^{-1} of PEG-creatine was associated with a significantly greater creatine uptake efficiency in skeletal muscle compared with 20 g · d^{-1} of CM over a 5-day supplementation period. Therefore, the authors (12) suggested that relatively smaller doses of PEG-creatine may improve measures of exercise performance to similar levels compared with larger doses of CM. Subsequently, Herda et al. (19) established that 30 days of supplementation with 1.25 and 2.50 g · d^{-1} of PEG-creatine provided ergogenic effects on 1RMBP and 1RM leg press equal to those from 5.0 g · d^{-1} of CM. Based on these findings (12,19), we hypothesized that 28 days of supplementation with the current PEG-creatine doses (1.25 and 2.50 g · d^{-1}) would result in increased $1RM_{BP}$ and $1RM_{LE}$. The physiological mechanism associated with PEG-creatine supplementation that is responsible for improving 1RMBP and 1RM leg press, but not 1RMLE remains uncertain. Specifically, dosing regimens as low as 1.25 g · d^{-1} of PEG-creatine have resulted in increased $1RM_{BP}$ and 1RM leg press; whereas, 1.25–5.00 g · d^{-1} has not led to improved $1RM_{LE}$. Thus, the present findings and those of others (5,13,19,34,39) have indicated that supplementation with PEG-creatine or CM may not influence measures of upper- and lower-body strength in similar manners.

In this investigation, muscular endurance was assessed as the maximum number of repetitions completed using 80% of the baseline (day 0) 1RM for both bench press and leg extension. Our results indicated that there were increases in REP_{BP} from day 0 to day 28 for the $PEG_{1.25}$ (7.4 ± 0.6 to 9.3 ± 0.5) and $PEG_{2.50}$ (8.7 ± 0.5 to 10.6 ± 0.6) groups, but no change in the placebo group (8.0 ± 0.4 to 8.9 ± 0.4). For REP_{LE}, however, there were increases from day 0 to day 28 for all 3 groups ($PEG_{1.25}$, 12.8 ± 0.8 to 19.7 ± 1.6; $PEG_{2.50}$, 12.8 ± 1.0 to 18.3 ± 1.6; placebo, 13.2 ± 0.9 to 18.6 ± 1.8). Previous studies have shown that short-term high-dosage CM supplementation (21,37), but not chronic low doses of PEG-creatine (19), improve upper- and lower-body muscular endurance. For example, loading with 20 g · d^{-1} of CM for 5 days increased muscular endurance at 60% 1RM for bench press (16.1 ± 2.9 to 18.8 ± 3.5) and 70% 1RM for half squat (13.2 ± 3.0 to 15.9 ± 2.1) (21). Warber et al. (37) also found that 24 g · d^{-1} of CM for 5 days resulted in significant increases in bench press repetitions to failure at 70% of 1RM (5 set total, 43.7 ± 6.9 to 50.7 ± 6.9) compared to placebo (41.4 ± 5.9 to 44.3 ± 5.9). Herda et al. (19), however, demonstrated that increases in bench press endurance (80% 1RM) and leg press endurance (80% 1RM) after 30 days of supplementation with 5 g · d^{-1} of CM, 1.25 g · d^{-1} of PEGcreatine, and 2.50 g · d^{-1} of PEG-creatine were not significantly different from those observed in the placebo group. Therefore, the results of this study and Herda et al. (19) suggested that the influence of low-dose (1.25–2.50 g · d^{-1}) PEG-creatine supplementation on muscular endurance in untrained individuals has not been clearly established. Furthermore, similar to previously reported findings on muscular strength, it is possible that supplementation with PEGcreatine may not influence measures of upper- and lower body muscular endurance in the same manner.

Although there is conflicting evidence (2,15,39), a number of previous studies (8–10,13,16,21,27,36,37) have shown increases in body mass of 1–2 kg after typical loading periods (5–6 days, 20–24 g · d^{-1}) with CM. In this investigation, the $PEG_{1.25}$ group exhibited increased body mass from day 0 (79.8 ± 2.0 kg) to day 28 (80.7 ± 2.0 kg), but not at day 14 (80.2 ± 2.0 kg). In addition, the $PEG_{2.50}$ group had increased body mass from day 0 (81.3 ± 2.1 kg) to day 14 (82.2 ± 2.1 kg) and day 28 (82.7 ± 2.1 kg). Changes in body mass that are commonly observed with CM supplementation have been attributed to increased body water content as the result of increased cellular osmolarity (20,36). Other findings (28,36), however, have suggested that creatine supplementation may also promote increases in FFM that are independent of those achieved with resistance training. For example, the cellular swelling that occurs during creatine supplementation because of increased intracellular water accumulation may serve as a "universal anabolic signal" (p. 140), thereby stimulating myofibrillar protein synthesis (36). The findings of Parise et al. (28) have also indicated that creatine may indirectly provide anabolic effects through the inhibition of protein catabolism. In this study, however, there were increases in FFM over the 28-day supplementation period for the $PEG_{1.25}$ (67.8 ± 1.4 to 69.0 ± 1.4 kg), PEG2.50 (67.7 ± 1.5 to 69.0 ± 1.5 kg), and placebo (66.7 ± 1.2 to 67.5 ± 1.3 kg) groups. Based on these findings and the time course (28 days) of this study, it is likely that the changes in body mass for the PEG-creatine groups were the result of increased intramuscular water, phosphocreatine, or glycogen. Future studies should further examine the relationships among PEG-creatine supplementation and body composition using various dosing protocols.

In summary, the present results indicated that supplementation with PEG-creatine led to improvements in vertical jump, 20-yard shuttle run, 3-cone drill, REP_{BP}, and body mass. Future studies should further examine the effects of PEG-creatine supplementation on standardized anaerobic performance measures, muscular strength and endurance as well as body composition using larger doses or longer supplementation periods.

Practical Applications

The results from this study indicated that PEG-creatine supplementation (1.25 or 2.50 g · d^{-1}) improved lower-body vertical power, upper-body muscular endurance, agility, change-of-direction ability, and body mass. Thus, these findings support the use of the PEG-creatine supplement, at the dosages examined in this investigation, as an ergogenic aid for increasing performance in vertical jump, REPBP, and body mass as well as improving 20-yard shuttle run and 3-cone drill times in untrained individuals. For strength and conditioning coaches, personal trainers, athletic trainers, physical therapists, educators, and other fitness professionals, the present results provide valuable information pertaining to supplementation based on the needs and goals of a client or athlete. For example, the current PEG-creatine supplement may be most beneficial at the initiation of a conditioning program or preseason workout routine during which the client or athlete is in an untrained state. In particular, supplementation with PEG-creatine may enhance the ability to maintain high-intensity exercise, thereby improving training capabilities and performance. For the individual involved in recreational sports, these findings also suggested that PEG-creatine supplementation may improve a number of anaerobic performance measures without a concurrent resistance training program.

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