Creatine supplementation improves muscular performance in older men

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ABSTRACT

GOTSHALK, L. A., J. S. VOLEK, R. S. STARON, C. R. DENEGAR, F. C. HAGERMAN, and W. J. KRAEMER. Creatine supplementation improves muscular performance in older men. *Med. Sci. Sports Exerc.*, Vol. 34, No. 3, pp. 537–543, 2002. **Purpose:** Creatine supplementation has been shown to enhance muscle strength and power after only 5–7 d in young adults. Creatine supplementation could therefore benefit older individuals because aging is associated with a decrease in muscle strength and explosive power. **Methods:** We examined the effects of 7 d of creatine supplementation in normally active older men (59–72 yr) by using a double-blind, placebo-controlled design with repeated measures. After a 3-wk familiarization period to minimize learning effects, a battery of tests was completed on three occasions separated by 7 d (T1, T2, and T3). After T1, subjects were matched and randomly assigned into creatine ($N = 10$) and placebo ($N = 8$) groups. After T2, subjects consumed supplements (0.3 $g \cdot kg^{-1} \cdot d^{-1}$) for 7 d until T3. All subjects were tested for maximal dynamic strength (one-repetition maximum leg press and bench press), maximal isometric strength (knee extension/flexion), upper- and lower-body explosive power (6×10-s sprints on a cycle ergometer), and lower-extremity functional ability (timed sit-stand test and tandem gait test). Body composition was assessed via hydrostatic weighing, and blood samples were obtained to assess renal and hepatic responses and muscle creatine concentrations. **Results:** No significant increases in any performance measures were observed from T1 to T2 with the exception of isometric right-knee flexion in the placebo group indicating stability in the testing protocols. Significant group-by -time interactions indicated the responses from T2 to T3 were significantly greater ($P \leq 0.05$) in the creatine compared with the placebo group, respectively, for body mass (1.86 and −1.01 kg), fat-free mass (2.22 and 0.00 kg), maximal dynamic strength (7–8 and 1–2%), maximal isometric strength (9–15 and −6 to 1%), lower-body mean power (11 and 0%), and lower-extremity functional capacity (6–9 and 1–2%). No adverse side effects were observed. **Conclusion:** These data indicate that 7 d of creatine supplementation is effective at increasing several indices of muscle performance, including functional tests in older men without adverse side effects. Creatine supplementation may be a useful therapeutic strategy for older adults to attenuate loss in muscle strength and performance of functional living tasks. **Key Words:** AGING, EXERCISE, ERGOGENIC AID, STRENGTH

Muscular strength and explosive power decrease slightly from 30 to 50 yr, and a steeper decline is observed around the sixth decade of life (3). The overall functional loss of strength during adult life is typically 30–40%, with most of the impairment of function occurring between 45 and 70 yr (2,23). A 25–35% reduction in muscle mass between 25 and 65 yr of age, due to motor unit losses and muscle fiber atrophy, is a primary factor responsible for the age-associated reduction in the contractile strength of muscle (10,13). Strength and power loss adversely affect activities of daily living (e.g., time to rise from a chair) and increase frequency of falls (1,12).

Our laboratory recently demonstrated that 7 d of creatine supplementation significantly increased dynamic muscular strength and power in young men (33,34). In contrast, data from recent studies indicate that maximal isometric arm strength and leg fatigue (assessed using an isokinetic knee-extension test) were not significantly enhanced after creatine supplementation in subjects 60–82 yr of age (26,27). There was, however, a significant interaction effect in these studies for the knee-extension tests, indicating that the delta change in performance was favorable for creatine subjects. A longer period of creatine supplementation (8 wk) in conjunction with a resistance-training program in elderly subjects 67–80 yr failed to result in significant increases in several measures of muscular performance (7). The lack of significant improvements from creatine supplementation in older men was not expected because aging is associated with slightly lower phosphocreatine resynthesis rates that improve to a greater extent upon supplementation compared with younger men (29). This study did not, however, measure muscle creatine concentrations.

Failure to detect a statistically significant effect of creatine supplementation on performance in older men may be partially attributed to insufficient reliability of strength assessment protocols (7). Several familiarization sessions to

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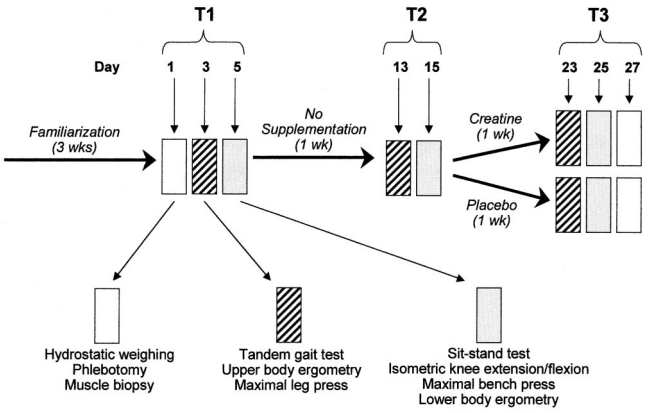

FIGURE 1—Experimental design.

establish reliability of maximal effort performances and control for day-to-day variability are critical in order to detect a statistically significant effect of a particular intervention, especially creatine supplementation because the increases in performance are typically about 5–10% (18,34). Furthermore, no studies have attempted to assess how increases in maximal exercise performance after creatine supplementation translate into performance of functional living tasks. In this study, we examine the effects of 7 d of creatine supplementation on body composition, dynamic and isometric muscular strength, explosive power, and lower-body functional living tasks in older men.

METHODS

Experimental approach. A double-blind, placebo-controlled design with repeated measures was used (Fig. 1). All subjects completed a battery of tests on three separate occasions after a 3-wk familiarization period involving the experimental tests to minimize potential learning effects. After the first battery of tests (T1), subjects were matched according to age, body mass, and physical performance. They were then randomly assigned in a double-blind fashion to a creatine or placebo group. Seven days after T1, subjects completed the same battery of tests to assess any learning effects (T2). Immediately after T2, subjects consumed their appropriate supplements for 7 d followed by the same battery of tests (T3).

Although a within-subjects (cross-over) experimental design has the advantage of controlling for any confounding variable(s) that may be present in one of the treatment groups, we utilized a two-group design because of potential problems with a cross-over approach in creatine supplementation studies that examine physical performance. The washout period for muscle creatine is long (about 4 wk) and only addressed in a few studies (22). Differences in dietary creatine intake during the washout period and intersubject variability in creatine accumulation and depletion are relatively unknown, complicating the use of a cross-over design. Furthermore, a 4-wk washout period between treatments would make data collection and testing reliability problematic.

Subjects. Twenty men between the ages of 59 and 73 were recruited for this investigation. All subjects were informed of the purpose and possible risks of this investigation before signing an informed consent document approved by the University Institutional Review Board. All subjects were screened by a physician, which included a graded exercise test with a 12-lead EKG. All subjects were determined healthy and free of any medical or orthopedic problems that would confound the data. Two subjects could not complete all the testing due to reasons unrelated to the study. The physical characteristics of the creatine and placebo subjects are shown in Table 1. No statistically significant differences were observed between the groups at the beginning of the study.

Supplementation protocol. After T2, subjects were provided with written instructions and capsules containing either creatine monohydrate (Creatine Fuel®, Twin Laboratories, Inc., Hauppauge, NY) or powdered cellulose placebo (0.3 g·kg body mass^{-1} divided into three equal dosages consumed with each meal) to be consumed for 7 d. This pattern of creatine administration has been shown to increase muscle creatine more than 20% in young men in our laboratory (33). We assessed creatine levels in the muscle to verify and support this approach. The subjects were also administered a 10-point Likert scale exit questionnaire to record changes in muscle cramps, gastrointestinal distress, and well-being to the supplementation protocol.

Familiarization protocol. In an effort to eliminate anticipated learning effects and establish reliability of all the testing protocols, six familiarization sessions were conducted over a 3-wk period before T1. The sessions consisted of repeated practicing of each protocol. The familiarization sessions involved teaching specific exercise techniques for each test and allowing submaximal practice. Maximal practice for each test took place 2–4 times (depending upon the test) in order to reduce any learning effects and allow for stability of the data (14). By the sixth familiarization session, intraclass R was ≥ 0.95 for each of the tests, indicating the elimination of the learning curve for the subjects.

Exercise-testing battery. The experimental exercise tests were completed over 2 d (see Fig. 1). Upper- and lower-body tests were alternated to minimize the effect of prior fatigue on subsequent tests. The lower-body functional tests were performed first each day because these tests would potentially be more sensitive to muscle fatigue from previous tests. The order of tests on day 1 consisted of the tandem gait test, upper-body ergometer test, and

TABLE 1. Physical characteristics of the subjects.

	Creatine (N = 10)	Placebo (N = 8)
Age (yr)	65.4 ± 1.5	65.7 ± 2.0
Height (cm)	177.0 ± 1.5	176.8 ± 1.7
Body mass (kg)	84.8 ± 2.8	86.5 ± 3.3
Fat-free mass (kg)	61.5 ± 2.1	62.1 ± 3.1
Body fat (%)	27.5 ± 1.3	28.2 ± 1.9
1 RM leg press (kg)	214.3 ± 11.9	212.6 ± 18.1
1 RM bench press (kg)	58.5 ± 2.8	58.4 ± 3.5

Values are mean ± SE; 1 RM, one-repetition maximum.

one-repetition maximum (1 RM) leg press. After 2 d of rest, day 2 testing involved the sit-stand test, isometric knee-extension/flexion strength, 1 RM bench press, and the lower-body ergometer test. There was 20 min of recovery between tests on each day.

Maximal dynamic and isometric strength. Dynamic lower-body strength was assessed on a leg-press machine (Berry Equipment, Cleveland OH). During familiarization, a range of motion equal to 110° at the knees was measured and marked on the leg press machine for each subject and used for all subsequent testing. Maximal dynamic strength of the upper body was determined on a Smith machine bench-press apparatus by using a standard grip in a supine position. A warm-up consisting of 8 repetitions at an estimated 50% of 1 RM, 5 repetitions at 70% of 1 RM, and 2 repetitions at 85% of 1 RM was performed before all attempts. The first attempt was at 95–100% of the estimated maximum and 5–20 lbs were added for subsequent trials. Three-minute rest periods were taken between all attempts. Maximal unilateral isometric force of the knee extensor and flexor muscles was recorded at a knee angle of 90° with a Biodex testing system (Biodex Medical Systems, Long Island, NY). Subjects were instructed to extend or flex the knee(s) as rapidly as possible upon command for four seconds. Peak force after five attempts was recorded.

Upper and lower-body anaerobic power. Peak anaerobic power of the upper and lower body was assessed using a modified 10-s Wingate test (5) on a mechanically braked cycle ergometer interfaced with a computer using SMI software (Sports Medicine Industries, Saint Cloud, MN). A warm-up was performed at 20% maximal intensity for 5 min with two interspersed 5-s sprints at the subject's prescribed test load. Three minutes after the warm-up, subjects performed five 10-s bouts with 2-min rest intervals against an opposing force equal to 0.05 and 0.075 kg·kg body mass^{-1} for the upper- and lower-body protocols, respectively. Flywheel revolutions were monitored via an electromagnetic detection system with printer interface during each 10-s bout. Total flywheel revolutions per second were recorded and used to calculate peak power (highest 1-s value) and mean power output for each 10-s bout.

Lower-body functional tests. To assess neuromuscular control under stressful conditions, lower-extremity functional performance was determined using a sit-stand and a tandem gait test (19). To test the ability to rise from a chair without using the arms, a straight-backed chair (40 cm high) on a rubber-matted floor was used. The subject was asked to sit and stand as fast as possible five times with arms folded across his chest. From a seated position with back in contact with the chair, upon the signal by the technician, the subject stood up and sat down as quickly as possible and was timed from the initial sitting position to the final standing position at the end of the fifth stand by using a digital stopwatch to the nearest 0.01 s. The tandem gait test consisted of subjects walking as fast as possible along a 6-m line with each foot in tandem position (heel of one foot directly in front of and in contact with the toe of the other foot). Subjects walked the entire 6-m line while being timed for speed. Six trials were conducted and the fastest time recorded.

Body composition. Body composition was determined at T1 and T3. Nude body mass was measured on a Toledo electronic scale (Reliance Electronic Co., Worthington, OH to the nearest 100 g. Body composition was assessed via hydrodensitometry in a stainless steel tank with scales based on the load-cell principle interfaced with recorder and computer. The residual volume method from vital capacity (9) was used to calculate residual volume. Percent body fat was calculated from body density (11).

Blood collection and analyses. Blood samples were obtained at T1 and T3. Blood samples were obtained between 7:00 and 8:30 a.m. after an 8-h overnight fast from an antecubital vein in the forearm with a needle and Vacutainer set-up. Hematocrit was obtained in triplicate via microcentrifugation. The remaining whole blood was allowed to clot at room temperature and was then centrifuged at 2000 $\times$ *g* for 10 min. The resultant serum was separated into six micro-tubes and stored at −81°C. The samples were thawed once and analyzed in duplicate for alanine aminotransferase (ALT), gamma glutamyltransferase (GGT), aspartate aminotransferase (AST), creatinine, and blood urea nitrogen (BUN) by using commercially available kits (Sigma Diagnostics, Saint Louis, MO) on a spectrophotometer (Milton Roy Spectronic 1201, Spectronic Instruments, Inc., Rochester, NY). All samples for each analyte were determined in the same assay and demonstrated intra-assay coefficients of variance $< 5\%$.

Muscle biopsies. To assess the extent of muscle creatine loading, biopsies (50–100 mg) were obtained from the superficial portion of the vastus lateralis muscle by using the percutaneous needle technique with suction (6,15) at T1 and T3. The extracted muscle was immediately frozen in isopentane cooled by liquid nitrogen to −160°C and stored at −80°C. Tissue samples were freeze-dried, weighed, extracted with perchloric acid, and analyzed in duplicate for ATP, phosphocreatine, and creatine by using fluorometric techniques (21). There were technical problems with the assay that precluded useful interpretation of the data, and thus muscle creatine values are not reported.

Statistical analyses. A two-way (group by time) analysis of variance (ANOVA) was used to evaluate the data across time and between groups. When a significant *F*-score resulted, a Fishers LSD *post hoc* test was used to determine pair-wise differences. Statistical power was determined to be ≥ 0.95 for all measures for the sample size used at the 0.05 alpha level (nQuery Advisor® software, Statistical Solutions, Saugus, MA). The level of significance was set at $P \leq 0.05$.

RESULTS

Maximal dynamic strength. Significant group-by-time interactions were observed for maximal bench press and leg-press strength (Fig. 2). There were no significant differences between T1 and T2 for both groups and from T2 to T3 for the placebo group. The creatine group demonstrated

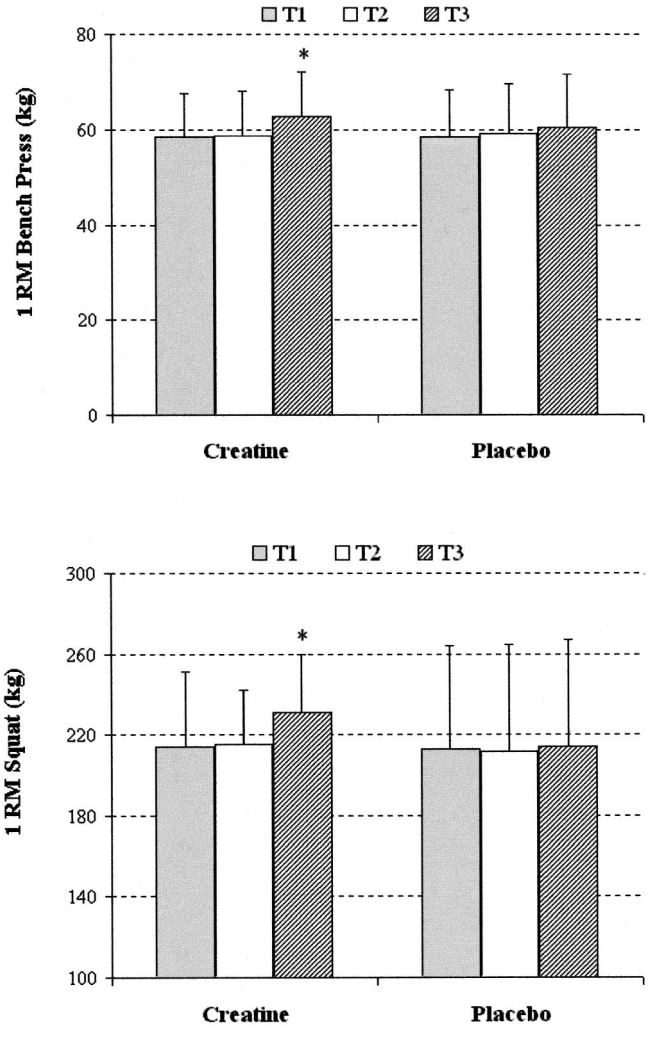

FIGURE 2—One repetition maximum (1 RM) bench press (upper panel) and squat (lower panel) at baseline (T1), after 7 d of no supplementation (T2), and after 7 d of either creatine or placebo supplementation (T3). *$P \leq 0.05$ from T2 to T3.

significant improvements in the bench press (4.1 ± 1.4 kg) and leg press (16.1 ± 4.4 kg) from T2 to T3.

Maximal isometric strength. Significant group-by-time interactions were observed for maximal isometric knee extension (left and right leg) and knee flexion (left leg only)(Table 2). There were no significant differences between T1 and T2 for both groups (except right-knee flexion in the placebo group) and from T2 to T3 for the placebo group. The creatine group demonstrated significant improvements in both left- and right-knee extension and left-knee flexion maximum force.

Ergometric power measurements. Significant group-by-time interactions were observed for lower-body peak power and mean power (Table 3). There were no significant differences in lower-body power between T1 and T2 for both groups and from T2 to T3 for the placebo group. The creatine group demonstrated significant improvements in lower-body peak and mean power from T2 to T3. There were no significant differences in upper-body peak or mean power at any time points for both groups.

Lower-body functional performance. Significant group-by-time interactions were observed for the sit-stand and tandem gait tests (Fig. 3). There were no significant differences in either test between T1 and T2 for both groups and from T2 to T3 for the placebo group. The creatine group demonstrated significant improvements (decreased time) in both tests from T2 to T3.

Body composition. Significant group-by-time interactions indicated that the creatine group gained significantly more body mass (1.86 ± 0.41 kg) and fat-free mass (2.22 ± 0.51 kg) compared with the placebo group (Table 4).

Blood analyses. There were no significant changes in either group for hematocrit, albumin, BUN, and liver enzymes. There was a significant increase in serum creatinine in the creatine (+9.5%) but not in the placebo (−0.3%) group (Table 5).

There were no significant differences between groups in blood pressure and Likert scores for muscle cramps, gastrointestinal distress, and well-being. After the study, subjects were asked which supplement they received. Six of the 10 creatine subjects (60%) and 4 of the 8 placebo subjects (50%) guessed they were given creatine.

DISCUSSION

Data from this study indicate that short-term creatine supplementation has a favorable effect on several measures of muscular performance in men aged 59–73 yr. Compared with a placebo group of similar physical characteristics, 7 d of creatine supplementation resulted in greater increases in body mass, fat-free mass, maximal dynamic strength, maximal isometric strength, lower-body explosive power, and lower-extremity functional capacity. These favorable outcomes mirror the responses reported in younger men by our laboratory (33,34) and other researchers (4,8,18). This is also the first study to demonstrate that increased overall body strength and increased rate of torque development after creatine supplementation translate into significant improvements in the ability to perform lower-body functional living tasks (i.e., rising from a chair a walking a straight

TABLE 2. Maximal isometric knee extension and flexion.

	Creatine (N = 10)	Placebo (N = 8)
Left knee extension (kg)		
T1	60.5 ± 10.4	65.7 ± 19.9
T2	61.1 ± 11.5	68.3 ± 22.8
T3	70.1 ± 11.6*	66.8 ± 19.1
Right knee extension (kg)		
T1	63.7 ± 10.2	64.4 ± 17.0
T2	63.6 ± 10.6	65.2 ± 18.6
T3	71.8 ± 9.8*	66.0 ± 19.7
Left knee flexion (kg)		
T1	26.3 ± 8.3	27.3 ± 6.5
T2	25.6 ± 7.0	27.5 ± 6.8
T3	28.5 ± 7.2*	27.8 ± 7.2
Right knee flexion (kg)		
T1	26.2 ± 7.8	24.9 ± 5.3
T2	25.7 ± 8.0	27.5 ± 5.9*
T3	28.1 ± 7.1	26.0 ± 5.6

Values are mean ± SE.
* $P \leq 0.05$ from corresponding T1 value.

TABLE 3. Lower-body and upper-body ergometry average peak powers and mean powers from five 10-s bouts.

	Creatine (N = 10)	Placebo (N = 8)
Lower-body average peak power ($W \cdot kg^{-1}$)		
T1	7.13 ± 1.19	7.69 ± 1.29
T2	7.13 ± 1.11	7.28 ± 1.22
T3	7.84 ± 1.28*	7.60 ± 1.18
Lower-body mean power ($W \cdot kg^{-1}$)		
T1	5.48 ± 0.90	6.29 ± 1.22
T2	5.56 ± 1.02	5.96 ± 1.22
T3	6.18 ± 1.49*	5.98 ± 0.94
Upper-body average peak power ($W \cdot kg^{-1}$)		
T1	5.14 ± 0.87	5.14 ± 1.34
T2	5.12 ± 0.83	5.17 ± 1.14
T3	5.59 ± 1.02	5.28 ± 1.03
Upper-body mean power ($W \cdot kg^{-1}$)		
T1	4.21 ± 0.85	3.86 ± 0.91
T2	4.08 ± 0.75	3.91 ± 0.86
T3	4.56 ± 1.10	4.00 ± 0.80

Values are mean ± SE.
* $P \leq 0.05$ from corresponding T1 and T2 value.

line). To address the experimental question in this study, we carefully matched older men and implemented a familiarization protocol to minimize any effect on the dependent variables arising from diminishment in muscle inhibition and/or learning effects generated by improvement in technique and coordination. The high test-retest reliability of all tests and lack of significant changes from T1 and T2 provide strong evidence that the significant improvements in muscular performance by the creatine group were due to creatine supplementation rather than a placebo or learning effect.

Seven days of creatine supplementation resulted in a significant increase in body mass (1.86 ± 0.41 kg) and fat-free mass (2.22 ± 0.51 kg), which is similar to results obtained from our laboratory in younger men (33) but not with results in older subjects (7,27). The acute increase in body mass has been hypothesized to be due to retention of body water (35); however, this notion has not been addressed with the best methodologies for measuring body water. An increase in body mass due to ingestion of water has been shown to influence hydrostatic weighing results by slightly increasing percent fat (16). Theoretically, if the entire weight gain resulting from creatine supplementation was due to water retention, then percent fat from hydrostatic weighing would be increased. However, creatine subjects in this study demonstrated a slight decrease in percent fat and a significant increase in fat-free mass. The acute increase in body mass after 1 wk of creatine supplementation may primarily be due to fluid retention, but some unknown quantity may be due to contractile protein accretion. However, any potential small increases in contractile protein would likely not play a major role in mediating gains in strength and power over the 1-wk supplementation period.

This is the first study to report significant increases (7–15%) in maximal dynamic strength of large muscles of the hip extensors/knee extensors (leg press) and chest and shoulders (bench press) as well as maximal isometric strength of smaller muscles of the quadriceps (knee extensions) and hamstrings (knee flexion) after 7 d of creatine supplementation in older men. Two studies in older men reported that creatine supplementation had no effect on maximal isometric arm-curl strength and leg fatigue assessed using an isokinetic knee-extension test (26,27). Although the testing protocols were different, there are consistencies between the data from Rawson et al. (26,27) and our findings. We both observed similar percent increases in leg-extension performance (8–14%), although the protocols differed in the type of muscle action performed (maximal isometric strength vs average torque production over 30 repetitions). We also both failed to observe any effect of creatine on upper-body performance of small muscle groups, although again the protocols were different (isometric arm-flexion strength vs upper-body ergometry). We did, however, observe increases in the bench press, which involves more upper-body musculature than an arm curl. We previously reported significant increases in maximal bench press strength after 7 d of creatine supplementation in younger men (33). These acute increases in maximal strength after creatine supplementation could be due to gains in fat-free mass (33) or an increased rate of phosphocreatine resynthesis during recovery

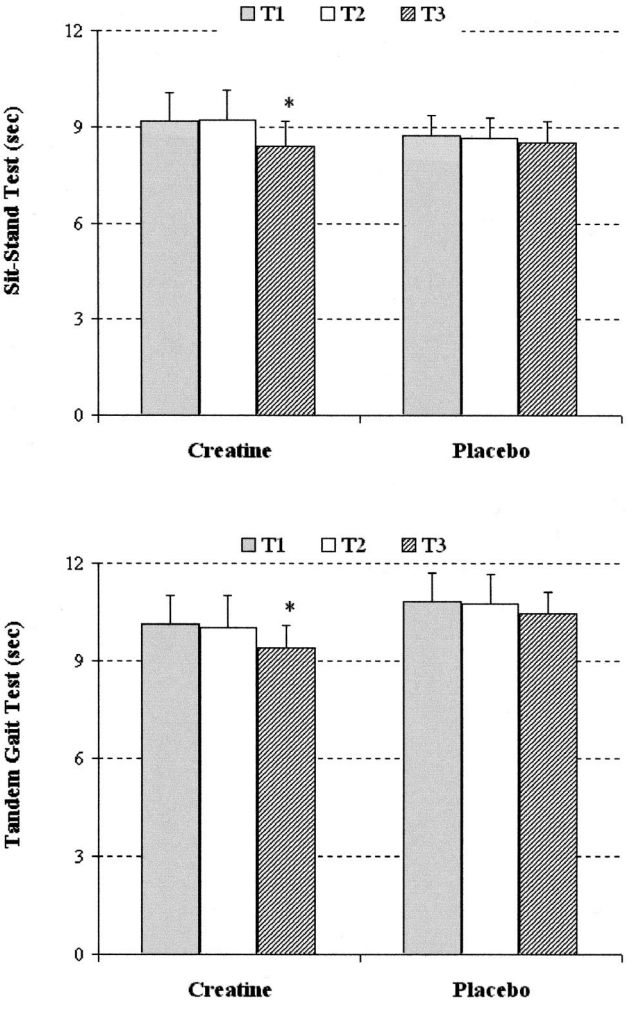

FIGURE 3—Time required to complete a sit-stand (upper panel) and a heel-toe walk (lower panel) test at baseline (T1), after 7 d of no supplementation (T2), and after 7 d of either creatine or placebo supplementation (T3). *$P \leq 0.05$ from T2 to T3.

between lifts (17,29). Both these explanations are unlikely given the short time period for gains in fat-free mass and the fact that recent work indicates phosphocreatine resynthesis is not enhanced after creatine supplementation (32). Nevertheless, the role of phosphocreatine resynthesis in mediating increases in performance remains unclear. The maximal leg-press and bench-press protocols in this study involved multiple submaximal and maximal attempts with 3-min recovery before the final attempt, and the maximal knee-extension/flexion protocol involved multiple attempts each lasting 4 s. These warm-up and testing protocols may have depleted phosphocreatine stores enough to benefit from an increased rate of phosphocreatine resynthesis in subjects supplemented with creatine. Creatine supplementation has been shown to increase the rate of phosphocreatine resynthesis to a greater extent in middle-aged compared with younger individuals (29).

Power output during intermittent cycle ergometry of the lower body, but not the upper body, was significantly increased after creatine supplementation. Creatine supplementation significantly increased maximal isometric strength during knee extension but not during isometric handgrip exercise (31), further suggesting that improvements are more evident in movements performed with a large muscle mass. Alternatively, lower-body power production may be more dependent on changes in body mass compared with the upper body and thus improve to a greater extent in creatine subjects who did in fact increase body mass. Body mass was shown to be positively correlated with maximal power and the ability to maintain power at high percentages of maximum in active men (24). Our results do, however, show a significant increase in power production of the lower body even when normalized per kilogram body mass, suggesting that other variables affect power production during cycling (24).

This is the first study to show that creatine supplementation significantly increases lower-body motor functional performance in older men. Functional tests included rapid and repetitive transference from a seated to a standing position without the use of the upper extremities (sit-stand test) and rapid ambulation along a line by using tandem foot placement (tandem gait test). Creatine supplementation resulted in a 6–9% reduction in the time required to complete these tasks without dysfunction. Both maximal strength and the ability to generate torque rapidly are important in the performance of these tasks in addition to balance and coordination. Aging is associated with significant decreases in the ability to develop ankle torque, which may adversely affect the capacity to recover balance, prevent loss of balance, or to carry out other time-critical actions that require moderate-to-substantial strengths (30). The time available to make initial responses to a postural disturbance is usually $<$300 ms (28), which is not enough time to develop maximal joint torque strengths (20). Creatine supplementation may have improved absolute strength and/or rate of torque development, which enhanced the ability to repetitively rise from a chair and walk a straight line.

There were no significant changes in serum liver enzymes or BUN. Serum creatinine was significantly increased but within normal ranges. Several other studies have reported similar increases in blood creatinine (25,33), which is simply a reflection of greater catabolism of muscle creatine and not indicative of renal dysfunction. There were no significant differences between groups in blood pressure and subjective scores for muscle cramps, gastrointestinal distress, and well-being. Thus, as other studies have documented, short-term creatine supplementation does not have any adverse effects on hepatic or kidney function and well-being.

In summary, short-term creatine supplementation resulted in an increase in strength and power in older adults without any adverse side effects. These favorable responses to creatine supplementation corroborate our findings in younger men (33,34) and extend the favorable effects to include older men. Further, creatine supplementation improved the ability to execute lower-body motor tasks important in maintaining health and independent living in older men. The long-term prophylactic use of creatine supplementation may be a useful therapeutic strategy for middle-aged adults to attenuate loss in muscle strength and the ability to exert force rapidly that is evident in aging.

TABLE 4. Body composition responses.

	Creatine (N = 10)	Placebo (N = 8)
Body mass (kg)		
Pre	84.81 ± 13.02	86.45 ± 17.11
Post	86.67 ± 14.21*	85.44 ± 16.30
Body fat (%)		
Pre	27.47 ± 4.24	28.19 ± 7.13
Post	26.84 ± 4.16	27.80 ± 6.73
Fat-free mass (kg)		
Pre	61.10 ± 6.58	61.35 ± 8.92
Post	63.32 ± 7.80*	61.35 ± 8.85

Values are mean ± SE obtained from hydrostatic weighing.
* $P \leq 0.05$ from corresponding Pre value.

TABLE 5. Biochemical responses.

	Creatine (N = 10)	Placebo (N = 8)
Hematocrit (%)		
Pre	46.0 ± 2.5	42.1 ± 4.1
Post	45.6 ± 1.9	42.8 ± 3.9
Albumin ($g \cdot L^{-1}$)		
Pre	40.4 ± 6.2	39.6 ± 4.9
Post	39.1 ± 5.7	40.2 ± 4.3
BUN ($mmol \cdot L^{-1}$)		
Pre	2.8 ± 1.3	2.7 ± 1.8
Post	2.7 ± 1.9	2.7 ± 1.5
ALT ($U \cdot mL^{-1}$)		
Pre	19.7 ± 17.4	18.8 ± 6.7
Post	19.6 ± 16.8	17.9 ± 5.9
AST ($U \cdot mL^{-1}$)		
Pre	32.9 ± 5.8	27.2 ± 6.9
Post	32.1 ± 9.0	27.4 ± 8.0
GGT ($U \cdot mL^{-1}$)		
Pre	18.2 ± 9.5	13.9 ± 5.1
Post	16.9 ± 5.7	14.5 ± 6.7
Creatinine ($\mu mol \cdot L^{-1}$)		
Pre	89.4 ± 15.7	87.6 ± 16.1
Post	97.9 ± 17.8*	87.3 ± 16.4

Values are mean ± SE; BUN, blood urea nitrogen; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, gamma glutamyltransferase.
* $P \leq 0.05$ from corresponding Pre value.

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