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ORIGINAL ARTICLE

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Neuromuscular properties and fatigue in older men following acute creatine supplementation

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Abstract The purpose of this study was to investigate the effects of creatine (Cr) supplementation in 12 older (65–82 years) men. The subjects were randomly assigned to a Cr or a placebo (P) group. Seven men were supplemented with 5 g of Cr and 5 g maltodextrin four times a day for 5 days (Cr), and 5 men consumed 5 g of maltodextrin four times a day for 5 days (P). Following this treatment body mass increased significantly in the Cr group (1 kg), but did not change in the P group, and measurements of arm anthropometry were not affected in either group. Prior to and following supplementation maximal isometric voluntary force (MVC), muscle activation, contractile properties and surface electromyography (EMG) were measured in the elbow flexor muscles at baseline, during a fatiguing task and over 10 min of recovery. The fatigue protocol involved both voluntary and contractile stimulated. Stimulated contractile properties, MVC, and muscle activation were not affected by Cr supplementation. Furthermore, there were no changes in time to fatigue, decline in MVC force, muscle activation, EMG or contractile properties during the fatigue protocol. The rates of recovery of voluntary force, and stimulated contractile force did not change following Cr supplementation. These results indicate that short-term Cr supplementation in older men does not influence isometric performance of the elbow flexor muscles.

Key words Strength · Aging · Electromyogram · Elbow flexor muscles

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Introduction

Following short-term (≤5 days) creatine (Cr) supplementation in young men, several investigators have reported an elevation in Cr and phosphocreatine (PCr) content (Harris et al. 1992; Balsom et al. 1993), an increase in body mass (Balsom et al. 1993), strength (Earnest et al. 1995; Maganaris and Maughan 1998), and endurance (Balsom et al. 1993). There are a limited number of studies, and the results are equivocal, with respect to the effects of Cr supplementation in older adults. It seems Cr supplementation in older adults results in an increase in endurance (Rawson et al. 1999; Rawson and Clarkson 2000) independent of any alteration in maximal strength (Bermon et al. 1998; Rawson et al. 1999; Rawson and Clarkson 2000) or body mass (Rawson et al. 1999; Rawson and Clarkson 2000). Further comparisons among the few studies (Smith et al. 1998; Rawson et al. 1999; Rawson and Clarkson 2000) of short-term Cr supplementation in older men are difficult because strength and endurance have not been measured in the same muscle groups and during similar tasks. The effect of acute Cr supplementation on endurance has been investigated during dynamic tasks in the lower limb (Rawson and Clarkson 2000), whereas strength has been investigated in isometric tasks in the upper limb (Rawson and Clarkson 2000). The effect of long-term (8 weeks) Cr supplementation on strength and fatigue has been reported in the same muscle groups and tasks (Bermon et al. 1998).

It has been suggested that the performance benefit of Cr supplementation occurs through an elevation in Cr and

PCr content (Harris et al. 1992; Balsom et al. 1993) which enables greater PCr hydrolysis for adenosine triphosphate (ATP) resynthesis (Terjung et al. 2000). Since the PCr content in skeletal muscle of older men is lower (Moller et al. 1980) than in young men, Cr supplementation may augment Cr and PCr content and enhance performance during an endurance task. Furthermore, if adenosine diphosphate rephosphorylation is more rapid and the removal of high energy phosphates faster following Cr supplementation it is likely that recovery from exercise will be quicker. No study has assessed the immediate recovery from fatigue in older men following Cr supplementation.

Force and endurance time can be affected by muscle activation, and this has not been measured in previous Cr supplementation studies in older men. Muscle activation is determined by central nervous system factors related to practice, effort (Gandevia et al. 1995) and neural drive (Bigland-Ritchie et al. 1986), and can be assessed objectively by using the techniques of twitch interpolation and surface electromyography (EMG). The application of these techniques could help determine whether changes in voluntary strength following Cr supplementation are due to peripheral changes in contractile, or because of central neural factors affecting muscle activation.

It has also been suggested that an increase in PCr content would increase exercise performance by increasing the supply of ATP which would enhance Ca^{2+} kinetics at the level of the sarcoplasmic reticulum, thereby decreasing contractile speed (Van Leemputte et al. 1999). Furthermore, since muscle relaxation accounts for a significant proportion of the energy required for muscle activity (Bergstrom and Hultman 1988) endurance times could be lengthened by faster contractile properties. Van Leemputtee et al. (1999) reported a decrease in relaxation time of a voluntary contraction in young men, and in one animal study electrically induced twitch relaxation times were decreased in adult rat soleus muscle after Cr supplementation (Wakatsuki et al. 1994). However, we did not find a change in electrically stimulated contractile properties in young men following Cr supplementation (Jakobi et al. 2000). Discrepancies may exist among these studies because of differences in measurement techniques, variations in fibre type among muscles and the role high energy phosphates play in human compared to animal muscle (Casey et al. 1996; Terjung et al. 2000). Since skeletal muscle of older men is slower (Porter et al. 1995) and has lower Cr and PCr stores (Moller et al. 1980) than muscle of young men it is possible that Cr supplementation may elicit greater changes in contraction time of old men compared to young men.

The purpose of this study was to combine neural and contractile measurements to investigate the effect of short-term Cr supplementation on muscle strength and fatigue in the elbow flexor muscles of older men.

Methods

The subjects were healthy, moderately active independent older men living in London, Ontario. The study was conducted according to the guidelines established by The University of Western Ontario Review Board for Research Involving Human Subjects and the Declaration of Helsinki. Informed written consent was obtained from the 12 older men (ages 65–82 years) prior to participation in the study. Daily physical activity (Robinson et al. 1999), diet, and caffeine consumption (Fryer and Neering 1989; Vandenberghe et al. 1996) were controlled by urging participants to maintain their standard daily activities and energy intake, to dissolve the powdered supplements in non-caffeinated beverages, and to abstain from consuming substantial amounts (e.g. more than one cup of coffee or equivalent) of caffeine for several hours prior to visiting the neuromuscular laboratory. Exclusion criteria included having received Cr supplementation within the previous 12 months, any myopathies or neuropathies, diabetes, alcoholism, or hypertension.

Study protocol

The subjects visited the neuromuscular laboratory on three separate occasions (habituation, pre- and post-test sessions) for this double-blind control study. A habituation session was conducted because prior reports in young adults (Maganaris and Maughan 1998) indicate that differences in force may exist between the first and second test as a result of familiarization with the experimental situation as well as learning how to perform maximal voluntary contractions (MVC). Approximately one half of the older men in this study performed consistently better voluntary contractions on the second session (pre), compared to the first (habituation). The second session was conducted 3–7 days following the first session, and the third session (post) was conducted within 8–14 h following the last day of dietary supplementation. Habituation involved positioning the subject in the arm device to ensure comfort and familiarity with the tests. Thorough measurements of arm, shoulder, head and hip placement were taken to ensure identical subject positioning during all test sessions. On the days of the pre- and post-tests, body mass (kilograms), height (centimetres) and arm anthropometry (Rice et al. 1990) were determined before assessment of strength, and performance of the fatigue protocol and recovery. Measurements of total arm cross-sectional area (centimetres squared) (TAA), muscle plus bone cross-sectional area (centimetres squared) (MBA), and skin plus subcutaneous tissue cross-sectional area (centimetres squared) (SST) were estimated from skinfold and arm girth measurements (Rice et al. 1990).

Of the 12 participants 7 were randomly assigned to the Cr supplementation group, while the remaining 5 subjects formed the placebo group (P). In addition to their normal diets the subjects took supplements four times a day for 5 days, the Cr group taking 5 g of powdered creatine mondohydrate blended with 5 g of maltodextrin, while the P group received 5 g of maltodextrin. Volunteers were instructed to dissolve the pre-weighed substance in warm water or a non-citric-acid juice and to consume a carbohydrate with the supplement (Green et al. 1996). The Cr and P samples were weighed and separated into 20 individual vials by someone not directly involved with the tests. Vials were given to each subject separately and the subjects did not compare samples, and the experimenters did not see the vials given to each subject.

Muscle strength

Elbow flexor muscle measurements were conducted with the subjects in a supine position on a padded examination table, with their legs elevated for comfort and as a means of preventing extraneous movement in the lower body, which might have influenced upper body positioning or force generation. The left elbow was flexed to 90° and the shoulders were secured to prevent extraneous movements of the trunk. The wrist was secured to a plate which was attached to a strain gauge (SST-700–100A, AS Technology) and the elbow was positioned and secured perpendicular to the wrist. The strain gauge was calibrated with known weights to confirm its linearity and to convert force values to newtons. The output from the strain gauge was sampled at 500 Hz, amplified and filtered

(60 Hz notch filter), and displayed in real time on an oscilloscope in front of the subject. After initial amplification and filtering, the force signal was converted from analogue to digital by a 12 bit converter (model 1401 Plus, Cambridge Electronic Design Ltd.).

To measure the MVC, the subjects were instructed to contract the elbow flexor muscles as intensely and as quickly as possible, and to maintain this effort for 4–5 s. The subjects performed 3–4 MVC during each session. The importance of exerting maximal effort during all contractions was verbally conveyed and reinforced, as well as visual feedback being provided. A 5 min rest was given between MVC and the highest value for each session was recorded as the maximum.. Muscle activation was assessed with the modified twitch interpolation technique (Hales and Gandevia 1988). This technique involved superimposing a series of paired electrical shocks (two pulses separated by 10 ms) during and following an MVC. If maximal effort was impaired a small twitch response would have been superimposed on the voluntary force curve. To obtain an estimate of muscle activation the amplitude of the interpolated double twitch (Ts) was compared to the amplitude of the post-MVC double twitch (Tr). A ratio of these two measurements provided an index of how well the muscle was activated {%activation = $[1 - (Ts/Tr)] \times 100$}. A benefit of employing this technique was not only to assess muscle activation, but also to monitor subject effort between sessions. It is unlikely that Cr would have altered activation but it was important to ensure that all tests were conducted with consistent maximal efforts which could be objectively monitored.

Contractile properties of the elbow flexor muscles were measured from twitch and tetanic recordings induced by electrical stimulation through carbon-rubber stimulation electrodes (4×4.5 cm) which were tightly bandaged over the proximal and distal portions of the flexor muscle area of the arm. The electrical pulse duration was 50 μs, the voltage was constant (400 V) and the current level was adjusted in incremental steps (model DS7H, Digitimer Ltd.). Stimulation intensity was set to a level which activated as much of the muscle as possible, or to the highest tolerable level without interference from antagonists. Palpation, noticeable contraction of the triceps brachii muscle, or a decrement in force with an increase in current, were monitored to determine whether antagonist muscles were activated. Identical stimulation settings were used for each test session. To induce twitches, two sets of 10 single pulses were delivered at 1 pulse·s^{-1} while the subjects were at rest. The two sets of pulses were separated by approximately 1 min. Off-line analysis of the twitches consisted of peak tension (PT), time to peak tension (TPT) and half relaxation time (HRT). To assess the twitch contractile quality approximately 16 single twitches were averaged to determine PT, TPT and HRT, and the intra-class correlation coefficients between the habituation and pre-test sessions for these measurements were 0.83, 0.86, and 0.86, respectively. For tetanic responses at rest, 16 pulses were delivered at 50 Hz for 320 ms duration. Stimulated tetanic contractions were elicited twice with 30 s rest given between each contraction. Peak tetanic tension (TT) and tetanic HRT were determined from the maximal response of these two contractions. The inter-day reliabilities for 50 Hz TT and HRT were both 0.95.

Surface EMG

A surface electrode was applied over the mid-belly region of the biceps brachii muscle approximately 5 cm from the cubital fossa, and a reference electrode was placed over the lateral epicondyle of the humerus. The EMG signal was sampled at 2,500 Hz, wide-band filtered (10 Hz–10kHz) and amplified (×500) using a pre-amplifier (amplifier and filter model NL824, Neurolog). After initial amplification and filtering, the EMG signal was converted from analogue to digital by a 12 bit converter (model 1401 Plus, Cambridge Electronic Design Ltd.). Off-line, the surface EMG was full-wave rectified and subsequently integrated (iEMG) over a 0.5 s interval. Force and EMG signals were monitored on the computer screen and sent on-line simultaneously to a VCR tape recorder.

Fatigue and recovery protocol

The fatigue protocol consisted of a series of target force contractions at 50% MVC for 6 s followed by 4 s of rest (0.60 work to rest ratio) until the maximal force became the target force of 50% MVC (Bigland-Ritchie et al. 1986), or the subjects would no longer continue. Fatigue was monitored by measuring maximal voluntary force and electrically evoked contractile properties every 60 s during the fatigue protocol. There were 16 pulses at 50 Hz stimulation applied to the resting muscle prior to the 50% target force which preceded the MVC. Before and during the MVC the subjects were stimulated with double pulses to assess the muscle activation, whereas following the MVC a single pulse was applied to assess contractile properties.

The recovery measurements at 1, 3, 5 and 10 min were the same as the tests applied every 60 s during the fatigue protocol. Off-line quantification of the single twitch and 50 Hz stimulation response consisted of PT, TT and peak rate of fall (newtons per millisecond, PRF). The PRF were measured, rather than HRT since the amplitude of the twitch and TT decreased during the fatigue protocol. This value was calculated by software differentiation of the force signal. Throughout the fatigue protocol and recovery EMG was collected. All EMG values were integrated and normalized to the pre-fatigue MVC.

The times used for all dependant variables in the fatigue protocol were start of fatigue (start), middle of fatigue (mid) and end of fatigue (end). This normalization procedure was necessary because not all subjects stopped the fatigue task at the same time.

Statistics

A two-factor repeated measurements analysis of variance using condition (Cr, P), and day (pre, post) was employed to determine whether there were any differences in non-fatigued baseline measurements of force, muscle activation or contractile properties. In addition, time to fatigue was analysed using a two-way repeated measurement analysis of variance (condition × day), while the remaining dependant variables for the fatigue protocol were analysed using a repeated measurement three-factor analysis of variance (condition × day × time of fatigue/recovery). The level of statistical significance was set at $P \leq 0.05$.

Results

None of the older subjects reported adverse side effects as a result of Cr or P supplementation, although all 12 subjects stated that urination was more frequent during the intervention period. This was probably due to an increase in fluid consumption which was necessary to dissolve the powdered substances. The mean ages [72 (SEM 2), 73 (SEM 3) years], heights [173 (SEM 4), 175 (SEM 4) cm] and body masses [83 (SEM 4), 81 (SEM 5 kg] of the Cr and P groups, respectively, were no different prior to supplementation. Following supplementation the body mass of the P group had not changed (range –0.7 to 0.4 kg), but the Cr group had a significant ($P \leq 0.05$) increase of 1 kg (range 0.3–2.8 kg) (Table 1). Anthropometric measurements of TAA, MBA and SST were no different between groups either before, or following dietary supplementation.

The mean MVC for the P group [277 (SEM 37) N compared to 277 (SEM 26) N] and Cr group [282 (SEM 28) N compared to 290 (SEM 22) N] had not changed after supplementation (Table 2). Similarly, stimulated single twitch contractile properties (TPT, HRT, PT) did not differ between groups, prior to or

Table 1 Subject characteristics

	Creatine				Placebo			
	Pre ($n=7$)		Post ($n=7$)		Pre ($n=5$)		Post ($n=5$)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Age (years)	72	2	–	–	73	3	–	–
Height (cm)	173	4	–	–	175	4	–	–
Body mass (kg)	83	4	84*	4	81	5	81	5
Total arm cross-sectional area (cm^2)	68	2	68	2	73	5	72	6
Muscle plus bone cross-sectional area (cm^2)	53	2	54	2	60	5	58	6
Skin plus subcutaneous tissue cross-sectional area (cm^2)	15	3	14	2	13	2	14	2

*$P \leq 0.05$ from pre to post

Table 2 Contractile properties of elbow flexor muscles prior to and following creatine or placebo supplementation

Muscle Property	Creatine				Placebo			
	Pre ($n=7$)		Post ($n=7$)		Pre ($n=5$)		Post ($n=5$)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Maximal voluntary contraction (N)	282	28	290	22	277	37	277	26
Activation (%)	96	2	97	1	94	1	95	2
Peak twitch tension (N)	16	2	17	2	13	2	14	2
Time to peak tension (ms)	73	4	69	4	73	4	72	3
Half relaxation time (ms)	56	4	59	7	67	6	68	4
50 Hz tension (N)	40	8	37	6	24	4	27	4
Tetanic half relaxation time (ms)	99	8	100	7	105	3	109	3
Peak rate of fall ($N \cdot ms^{-1}$)	–0.3	0.06	–0.3	0.09	–0.3	0.06	–0.3	0.08

following treatment (Table 2). In addition, the 50 Hz tension and HRT were neither influenced by Cr supplementation, nor were they different between the Cr and P groups (Table 2).

The range in time to fatigue for the pre- (5–38 min) and post- tests (4–42 min) were similar between the groups irrespective of the treatment. The Cr group had a non-significant increase of 1 min in mean time to fatigue following supplementation [from 21 (SEM 5) min to 22 (SEM 5) min], while the P group had a non-significant decrease [from 23 (SEM 4) min to 22 (SEM 4) min] of 1 min mean endurance time in the fatigue task. During the fatigue task, there was a significant decline ($P \leq 0.05$) in voluntary force to 65% of the initial MVC in both groups prior to and following supplementation (Fig. 1). In both groups the range in which force decreased was 49%–73% of the initial MVC.

A recovery of 1 min (R1) resulted in a 10% increase in voluntary force from the end of fatigue for both groups, but, at R1 voluntary force was still significantly lower than the pre- fatigue MVC in both groups. After a recovery of 10 min (R10) MVC force was still significantly less (~22%) than the pre- fatigue force (Fig. 1). Although muscle activation varied by about 10% over the fatigue protocol and recovery (Fig. 1), it was never significantly less than the pre- fatigue value in either group.

During fatigue, TT at 50 Hz was no different between groups and did not change as a result of dietary supplementation (Fig. 2). Tetanic force decreased by about 57% and had not recovered by R10. In accordance with other similar fatigue studies (Edwards et al. 1977; Bigland-Ritchie et al. 1986), single twitch tension declined substantially during the fatigue protocol to a level which precluded accurate measurements of contractile properties. The point at which the twitch force could no longer be measured did not change as a result of Cr supplementation.

There was a significant decrease in PRF (newtons per millisecond) of TT during the fatigue task. The rate slowed by about 67% from the initial pre-fatigue value in each group and was not influenced by dietary supplementation (Fig. 3). The PRF was similar between groups, and at R10 PRF was still significantly slower (~63%) than pre-fatigue (Fig. 3).

During the fatigue protocol and recovery maximal iEMG did not change in either group prior to, or following supplementation (Fig. 4). In each group the submaximal iEMG was initially 40% of maximal iEMG, had increased to about 60% at the mid point of fatigue, and, at the end of the fatigue task it was 70% of the maximal iEMG (Fig. 4). Submaximal iEMG did not recover in either group, it remained significantly greater (~28%) than the pre-fatigue level prior to and following supplementation (Fig. 4).

Discussion

In this study a variety of neuromuscular parameters were measured to determine whether short-term Cr

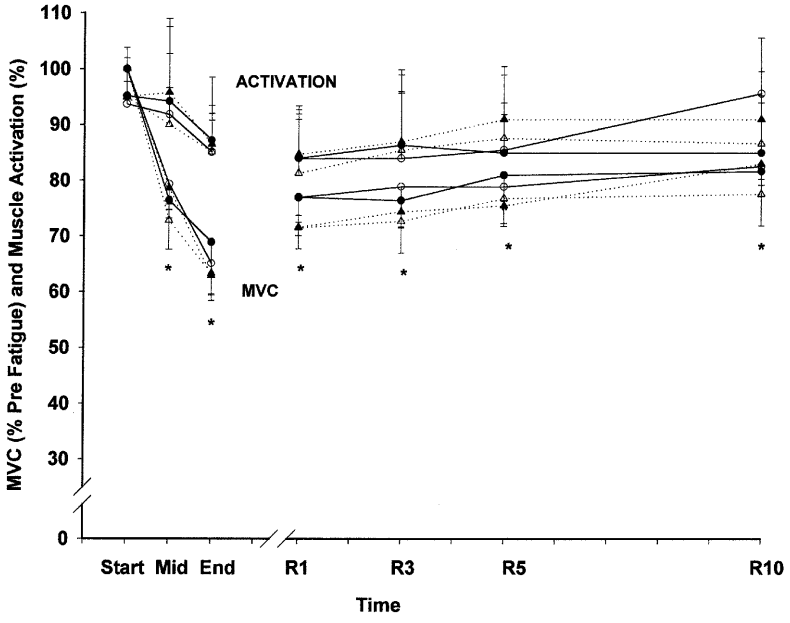

Fig. 1 Maximal voluntary contraction (*MVC*) and activation changes during fatigue and recovery. The MVC force and activation {%activation = [1 − (Ts/Tr)] × 100}, where Ts is the amplitude of the interpolated double twitch and Tr is the amplitude of the post-MVC double twitch have been normalized to their pre-fatigue values and presented on a relative scale as *start*, *middle* and *end*. Recovery is shown in real time at 1, 3, 5 and 10 min (*R1*, *R3*, *R5*, *R10*). There were no statistical differences between the creatine and placebo groups during fatigue or recovery. *Circles* and *solid lines* represent creatine, *triangles* and *dashed lines* represent placebo. All pre points are *open symbols*, post are *filled*. Standard error of the mean (SEM) for force are the *downward bars*, whereas SEM for muscle activation are the *upward bars*. *Significant difference ($P \leq 0.05$) from pre-fatigue values

supplementation influences the isometric contractile properties of the elbow flexor muscles of older men. The Cr supplementation had no effect on MVC, muscle activation, stimulated tensions and times at baseline, or during a submaximal voluntary fatigue task, and recovery. Although the older men showed a 1.0 kg increase in body mass, there was no change in arm size as measured by anthropometry.

In agreement with previous studies, in which no change in body composition (Rawson et al. 1999; Rawson and Clarkson 2000), or thigh muscle volume (Bermon et al. 1998) were reported, we observed no change in the measurements of TAA, MBA, or SST. The 1.0 kg increase in mass is consistent with studies of young men (Terjung et al. 2000), and one study in older men (Rawson and Clarkson 2000). A significant increase in body mass is not a consistent finding in the few studies in older men (Bermon et al. 1998; Rawson et al. 1999; Rawson and Clarkson 2000). It is possible that

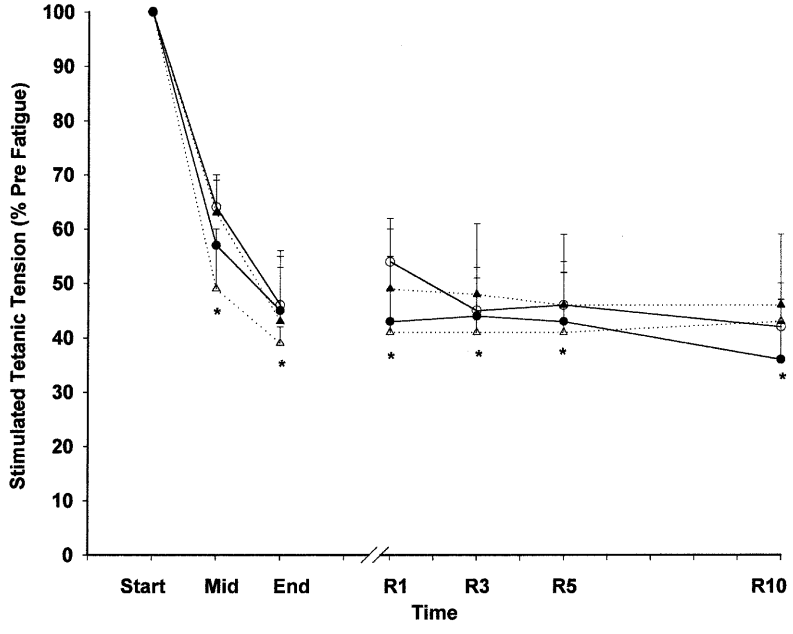

Fig. 2 Tetanic tension during fatigue (*start*, *middle*, *end*) and recovery at 1, 3, 5 and 10 min (*R1*, *R3*, *R5*, *R10*) have been normalized to the pre-fatigue value. There were no statistical differences between creatine and placebo groups prior to or following supplementation. *Circles* and *solid lines* represent creatine, *triangles* and *dashed lines* represent placebo. All pre-data are *open*, post are *filled*. *Significant difference ($P \leq 0.05$) from pre-fatigue

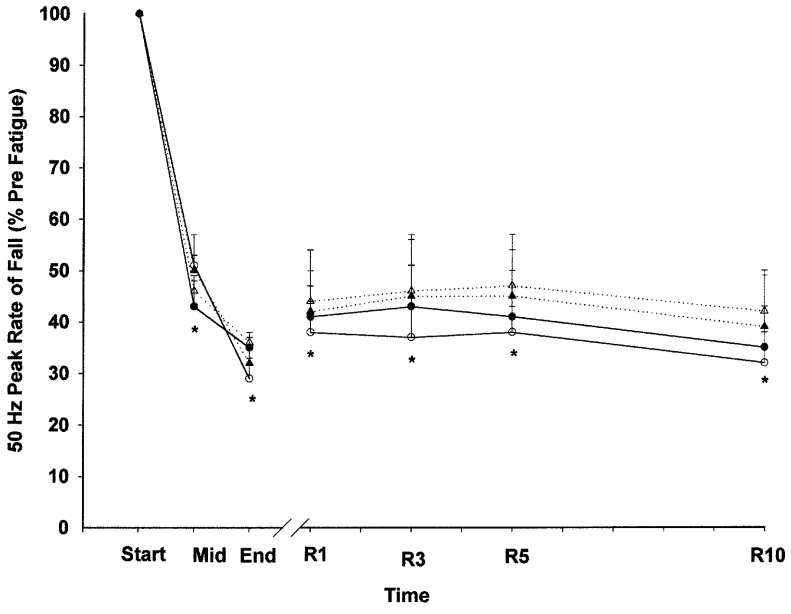

Fig. 3 The 50 Hz peak rate of fall for the pre- and post-fatigue test have been normalized to the initial pre-fatigue value. There were no statistical differences between groups or sessions. *Circles* and *solid lines* represent creatine, *triangles* and *dashed lines* represent placebo. All pre-data points are *open*, post are *filled*

differences exist between studies and age groups because of non-responders. Uptake and transport of Cr is mediated by insulin activity (Steenge et al. 1998) and is inversely related to the initial Cr content (Terjung et al. 2000). Since all of these factors differ among individuals (Dolan et al. 1995), it is probable that Cr uptake will vary between individuals. However, the literature suggests (Terjung et al. 2000) that an increase in mass is indicative of water retention related to an osmotic load caused by Cr retention (Ziegenfuss et al. 1998).

To elicit an increase in maximal voluntary force either muscle activation, or contractile tissue content need to be increased. In this study we incorporated an habituation session to ensure that subjects were familiar and comfortable with the experiment procedures and that the task under investigation (isometric elbow flexion) had been practised prior to the pre-test. Approximately one half of the subjects performed better subsequent to habituation. Furthermore, we used the twitch interpolation technique to ensure consistency in subject effort and found that there was no difference in muscle activation between the pre- and post-test for either the P or Cr groups. We observed no change in maximal voluntary force following supplementation. Our results in older men are similar to those of Rawson and Clarkson (2000), in that maximal isometric elbow

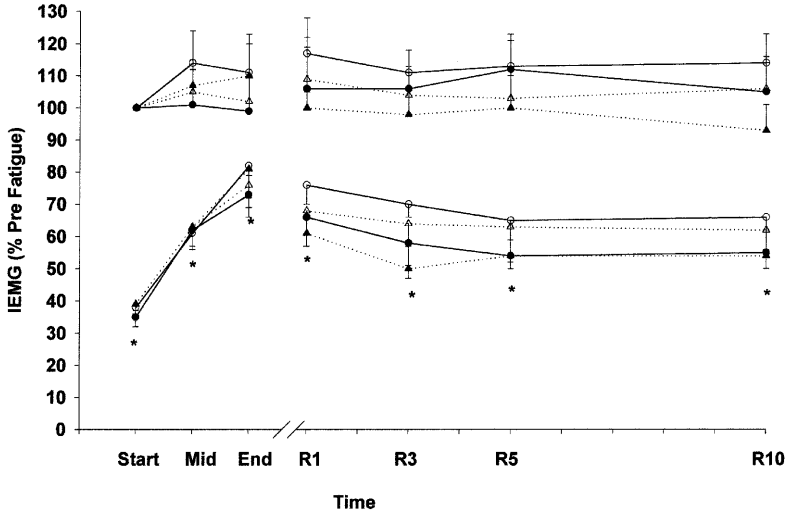

Fig. 4 Submaximal and maximal integrated electromyogram (*iEMG*) for the creatine and placebo groups have been normalized to the maximal iEMG recorded for the pre-fatigue maximal voluntary contraction. *Circles* and *solid lines* represent creatine, *triangles* and *dashed lines* represent placebo. All pre-data points are *open*, post are *filled*. Standard error of the mean (SEM) bars for maximal iEMG are *upward*, whereas SEM bars for submaximal iEMG are *downward*. There were no significant differences between groups on the pre- and post-test sessions. Submaximal iEMG increased significantly while maximal iEMG did not change during the fatigue protocol. *Significant differences ($P \leq 0.05$) from prefatigue values

flexion force in older men is not altered following Cr supplementation.

Slowing of twitch contraction and relaxation times have been reported for many skeletal muscles in aged humans (Roos et al. 1997), but to date there has been no attempt to measure contractile properties following Cr supplementation in older men. In this study electrically stimulated twitch tensions were small compared with MVC measurements (~6%), and thus as suggested by others (Edwards et al. 1977; Hanchard et al. 1998) may not be representative of the properties of the whole muscle, unless stimulated tests generate forces of 10% of MVC. Furthermore, twitches are less reliable [intra-class correlation (ICC) range 0.83–0.86] and much more affected by fatigue (Edwards et al. 1977) than higher frequency responses (ICC 0.95), and thus the 50 Hz responses (13% of MVC force) are often preferred to provide consistent measurements of contraction relaxation times, or rates in whole human muscle (Wiles et al. 1979; Cooper et al. 1988; Hanchard et al. 1998). In non-fatigued muscle of the older men 50 Hz TT, HRT and PRF did not change following Cr supplementation. Since measurements stimulated contractile properties reflect Ca^{2+} activity (Hunter et al. 1999), these results suggest that at least in the short term Cr does not alter Ca^{2+} activity.

The mechanism by which Cr could prolong time to fatigue is believed to be related to increased ATP resynthesis through the creatine kinase reaction (Casey et al. 1996; Terjung et al. 2000). If this reaction can be altered through enhanced PCr stores, conceivably older adults would be able to maintain everyday activities for longer periods of time. Furthermore, since muscle relaxation is an important component of the proportion of energy required for muscle work (Bergstrom and Hultman 1988), fatigue could be delayed by factors related to contractile speed. Indeed, an increase in the supply of ATP, which is known to alter Ca^{2+} kinetics at the level of the sarcoplasmic reticulum (Duke and Steele 1999), may decrease relaxation time (Van Leemputtee et al. 1999). However, our results showed muscle relaxation was not faster in older men following Cr supplementation and the endurance time in isometric elbow flexions was not prolonged. In addition, when young men performed an identical fatigue task Cr supplementation did not increase endurance time or decrease muscle relaxation time (Jakobi et al. 2000). Although previous studies have not evaluated changes in relaxation rate in older men after Cr supplementation, studies of dynamic knee extension have shown increases in time to exhaustion of about 4% in older men (Rawson and Clarkson 2000) and 30% in men and women (Smith et al. 1998). Comparisons of the results of fatigue studies are difficult because of task specificity since not only does the rate of fatigue differ between dynamic and isometric movements, but between different muscle groups, between maximal and submaximal tasks (Bigland-Ritchie et al. 1995) and possibly with sex (Terjung et al. 2000). Thus, it is unclear from the results of these few studies available whether, or to what extent Cr supplementation affects fatigue in a single limb task.

As well as changes in contractile activity, changes in muscle activation would also alter isometric endurance time. In this study muscle activation was assessed by the twitch interpolation technique and EMG. Previous studies of Cr supplementation in older men have not used these techniques in combination with a well-established voluntary fatigue protocol (Bigland-Ritchie et al. 1986). Muscle activation, and maximal iEMG remained near 100%, and the submaximal iEMG increased over the duration of the fatigue task, both prior to and following supplementation. These results are consistent with the literature for this task (Bigland-Ritchie et al. 1986), but more importantly indicate that acute Cr supplementation in older men does not increase muscle activation, which could prolong fatigue. There are a limited number of studies available on recovery from fatigue in older adults. Data from the present 12 older adults indicate that in the 10 min following a 50% submaximal voluntary isometric elbow flexion task, force and submaximal EMG do not recover to pre-fatigue levels. This lack of recovery was not influenced by 5 days of Cr supplementation.

In conclusion, we found short-term Cr supplementation increases body mass but does not alter maximal strength, contraction properties, time to fatigue or recovery in older men. The 1.0 kg gain in mass which we observed in these healthy older men is similar to the values reported for young men, which suggests that aged human muscle can Cr load. Following 5 days of supplementation, this mass gain did not result in a change in any of the measurements we made of muscle strength and fatigue. Perhaps the benefit of Cr supplementation may only occur in older men subsequent to long-term supplementation.

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