Original Article

Influence of Creatine Supplementation on the Parameters of the "All-out Critical Power Test"

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We tested the hypotheses that creatine loading would result in no alteration in critical power (CP) or the total work done > CP (W′) as estimated from a novel 3-minute all-out cycling protocol. Seven habitually active male subjects completed 3-minute all-out tests against fixed resistance on an electrically-braked cycle ergometer after a 5-day dietary supplementation with 20 g · d^{-1} of a glucose placebo (PL) and the same dose of creatine monohydrate (CR). The CP was estimated from the mean power output over the final 30 seconds of the test and the W′ was estimated as the power-time integral above the end-test power output. Creatine supplementation resulted in a significant increase in body mass (from 80.4 ± 9.2 kg to 81.5 ± 9.5 kg; $p < 0.05$), whereas the body mass was not different after placebo supplementation (80.3 ± 9.3 kg; $p > 0.05$). There were no differences in the power outputs measured during the 3-minute all-out tests following PL and CR supplementation (CP—PL: 252 ± 30 W *vs.* CR: 255 ± 28 W, $p > 0.05$; W′—PL: 19.4 ± 3.5 kJ *vs.* CR: 19.2 ± 3.4 kJ, $p > 0.05$; total work done—PL: 64.8 ± 4.9 kJ *vs.* CR: 65.0 ± 4.9 kJ, $p > 0.05$). Creatine loading had no ergogenic effect on the CP measured using the novel all-out protocol. In contrast to earlier studies which established the power-duration relationship using the conventional protocol, the finite work capacity > CP (W′) for all-out exercise was not enhanced by creatine loading. [*J Exerc Sci Fit* • Vol 7 • No 1 • 9–17 • 2009]

Keywords: all-out cycling, anaerobic work capacity, critical power, phosphocreatine, power-duration relationship

Introduction

The relationship between power output and the time to exhaustion is characterized by a hyperbolic function, which is defined by the power asymptote (critical power, CP) and the curvature constant (W′) (Fukuba et al. 2003; Monod & Scherrer 1965). The CP represents the boundary between the heavy and severe exercise intensity domains (Jones et al. 2008a; Poole et al. 1988) and is closely associated with the so-called "maximal lactate steady state" (Pringle & Jones 2002). The W′ parameter, which indicates that a fixed amount of work can be performed above CP, is purported to represent the energy available from the high-energy phosphate stores (adenosine triphosphate [ATP] and phosphocreatine [PCr]), anaerobic glycolysis and the small amount of stored oxygen (Gaesser et al. 1995; Moritani et al. 1981). The magnitude of the W′ might also be limited by the accumulation of fatigue-related metabolites within the contracting muscles (Jones et al. 2008a; Ferguson et al. 2007).

The power-duration relationship is conventionally established by performing three to five exhaustive high-intensity constant-work-rate exercise trials on separate days (Hill 1993). Recent evidence indicates, however, that the CP and W′ can also be established in a single 3-minute all-out cycling test, thus eliminating the need for numerous laboratory visits by the test participants

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(Vanhatalo et al. 2008a, 2008b; Burnley et al. 2006). The rationale for the all-out protocol derives from the two-parameter CP model which posits that the magnitude of the W′ remains constant regardless of the rate of its expenditure (Poole et al. 1988; Monod & Scherrer 1965). It has been demonstrated that the highest power output that can be elicited by voluntary effort at the end of the 3-minute all-out test closely approximates the CP (coefficient of variation, 2%), while the W′ can be estimated as the power-time integral above the end-test power output (coefficient of variation, 12%) (Vanhatalo et al. 2007).

Earlier studies which established the power-duration parameters using the conventional prediction trial protocol have demonstrated that prior high-intensity exercise, which would be expected to deplete intramuscular PCr and result in accumulation of fatigue-related metabolites such as H^+ and P_i, reduced the magnitude of the W′ without affecting the CP (Ferguson et al. 2007; Heubert et al. 2005). We recently demonstrated that prior sprint exercise similarly reduced the W′ with no effect on the CP when the power-duration parameters were estimated using the 3-minute all-out test protocol (Vanhatalo & Jones 2009). Conversely, dietary supplementation with creatine monohydrate, which is known to increase the intramuscular PCr content (Finn et al. 2001; Casey et al. 1996; Harris et al. 1992), has been shown to result in a significant increase in the conventionally estimated W′ parameter with no effect on the CP in two studies (Miura et al. 1999; Smith et al. 1998), though not in a third in which the W′ was not significantly altered (Eckerson et al. 2005).

The sensitivity of the W′ parameter to prior exercise in both the conventional and all-out protocols (Vanhatalo & Jones 2009; Ferguson et al. 2007; Heubert et al. 2005), along with the close agreement between parameter estimates derived from the two different protocols (Vanhatalo et al. 2008a, 2007), might indicate that W′ could be increased by creatine supplementation during the all-out test since this effect has been reported previously using the conventional protocol (Miura et al. 1999; Smith et al. 1998; but see also Eckerson et al. 2005). On the other hand, evidence that dietary creatine intake could improve performance during a single, prolonged bout of all-out exercise is limited. While some (van Loon et al. 2003; Jones et al. 1999; Balsom et al. 1995), though not all (Van Schuylenbergh et al. 2003; Finn et al. 2001), studies have reported improved performance in short-duration and/or intermittent all-out exercise, creatine loading did not increase the total work done over 60 seconds of all-out exercise (Schneider et al. 1997). Given that over 95% of the W′ is utilized over the first 90 seconds of all-out cycling (Vanhatalo et al. 2008b), these data indicate that the W′, as measured in the 3-minute all-out test, might not be enhanced by creatine loading. It therefore remains unclear how the CP and W′ parameters as estimated by the novel all-out test protocol might respond to a creatine loading intervention.

In light of the above, the present investigation was designed to test the hypotheses that when the power-duration parameters are established using the novel all-out test protocol, a 5-day creatine loading intervention would result in no alteration in either the CP or the W′.

Methods

Participants

Seven habitually active male participants (mean ± SD: age, 23 ± 6 years; stature, 1.84 ± 0.07 m; body mass, 80.4 ± 9.2 kg) volunteered to take part in this study which had been approved by the local research ethics committee and was conducted in accordance with the Declaration of Helsinki. Testing procedures were fully explained prior to obtaining written consent from each participant. All participants had previously taken part in at least one study carried out in the same laboratory using the 3-minute all-out cycling test and had not consumed any dietary supplements within 12 months preceding this study. Participants were instructed to be adequately hydrated and not to have consumed alcohol for 24 hours, and food or caffeine for 3 hours before each test.

Experimental overview

Participants made four visits to the laboratory over a period of 3 weeks (Figure 1). First, the participants performed a ramp incremental test for the assessment of peak oxygen uptake ($\dot{V}O_2$ peak) and the gas exchange threshold (GET). Following a minimum of 24 hours of recovery, participants returned to the laboratory and performed a 3-minute all-out test which served as a familiarization trial and was not included in the subsequent data analysis. The participants were then prescribed 5 days of dietary supplementation with glucose placebo, after which they performed one 3-minute all-out test (PL trial). The participants then underwent a 5-day supplementation period with creatine monohydrate before completing a final 3-minute all-out test (CR trial). Sequential administration of supplements was preferred over a cross-over design in order to minimize

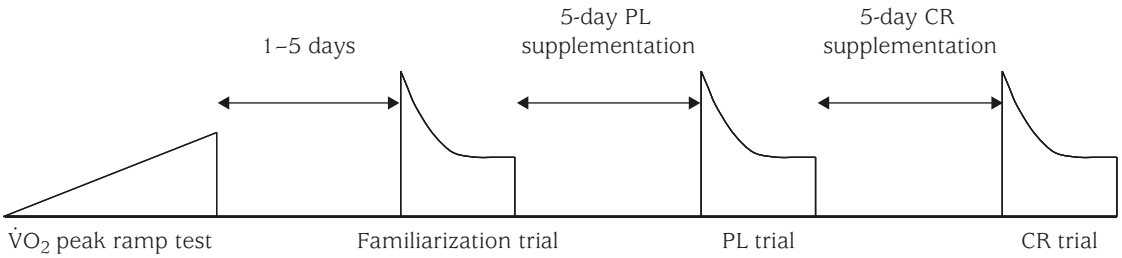

Fig. 1 Schematic illustration of the experimental overview. See text for details.

effects of temporal fluctuation in fitness levels and other uncontrollable variables over the approximated 6-week wash-out time required for total muscle creatine to reach baseline values following supplementation (Hultman et al. 1996). Furthermore, no sequential "learning effect" had been detected in the 3-minute all-out test performances of the same participants taking part in previous projects in the same laboratory. The initial familiarization trial was prescribed in order to demonstrate the lack of learning effect on the all-out effort of these experienced test subjects. The participants were blind to the order of supplements used and no feedback on test performance was given until all experimentation had been completed.

Determination of $\dot{V}O_2$ peak and GET

All exercise testing was conducted using an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). The ergometer seat and handlebar were adjusted for comfort, and settings were replicated for subsequent tests. The ramp protocol consisted of 3 minutes of unloaded baseline pedaling, followed by a ramp increase in power output of 30 $W \cdot min^{-1}$ until volitional exhaustion. Participants were instructed to maintain their chosen preferred cadence (80 rpm, $n = 6$; 90 rpm, $n = 1$) for as long as possible. The test was terminated when pedal rate fell more than 10 rpm below the chosen cadence for more than 5 seconds despite strong verbal encouragement.

Pulmonary gas exchange was measured breath-by-breath during the incremental test. The subjects wore a nose-clip and breathed through a low dead-space, low-resistance mouthpiece and a digital volume transducer turbine assembly (Metamax 3B, Cortex Biophysik, Leipzig, Germany). The inspired and expired gas volume and gas concentration signals were continuously sampled, the latter using electrochemical cell (O_2) and infrared (CO_2) analyzers (MetaMax 3B, Cortex Biophysik) via a capillary line connected to the mouthpiece. These analyzers were calibrated before each test with gases of known concentration, and the turbine volume transducer was calibrated using a 3 L syringe (Hans Rudolph, Kansas City, MO, USA). Gas exchange data were reduced to 10-second averages for the estimation of GET using the V-slope method and the $\dot{V}O_2$ peak was determined as the highest average $\dot{V}O_2$ over a 30-second period.

Three-minute all-out tests

Before each trial, participants performed a 5-minute warm up at ~90% GET, followed by 5 minutes of rest. The test began with 3 minutes of unloaded baseline pedaling, followed by a 3-minute all-out effort. Participants were asked to accelerate to 110–120 rpm over the last 5 seconds of the baseline period. The fixed resistance on the flywheel during the 3-minute all-out test was set using the linear mode of the Lode ergometer so that the participant would attain the power output halfway between the GET and $\dot{V}O_2$ peak (50% Δ) on reaching their preferred cadence (linear factor = power/preferred cadence^2). Strong verbal encouragement was provided throughout the test, but participants were not informed of the elapsed time in order to prevent pacing. To ensure an all-out effort, participants were instructed to attain their peak power output as quickly as possible at the start of the test and to maintain the cadence as high as possible at all times throughout the 3 minutes. The CP was calculated as the mean power output over the final 30 seconds of the test and the W′ was calculated as the power-time integral above CP. Blood samples (~25 μL) were collected from a fingertip into capillary tubes at rest prior to the test and immediately after the completion of the test. Samples were subsequently analyzed for blood lactate concentration (blood [lactate]) using an automated lactate analyzer (YSI Stat 2300, Yellow Springs, OH, USA), which was calibrated hourly using the manufacturer's standard (YSI 2747). Blood lactate accumulation (Δ blood [lactate]) was calculated as the difference between blood [lactate] at the end of exercise and blood [lactate] at rest.

Supplementation

During the first 5-day supplementation period, participants were prescribed a $4 \times 5\,g \cdot d^{-1}$ dose of glucose (placebo). During the second 5-day supplementation period, participants were given a $4 \times 5\,g \cdot d^{-1}$ dose of creatine monohydrate. The 5-day creatine loading dose applied in this study has been previously shown to be effective in significantly increasing the intramuscular phosphocreatine content (Hultman et al. 1996; Harris et al. 1992). Participants were instructed to consume the supplements, dissolved in a warm drink, at regular intervals throughout the day with a meal where possible and to avoid simultaneous caffeine intake in order to aid creatine intake. Participants were also given a journal for each supplementation period and were asked to log the times supplements were ingested. Self-reported compliance to supplementation across the group was 100%. The body mass was measured during the first laboratory visit and on day 6 from the commencement of each supplementation period as the participants returned to the laboratory for the performance of the 3-minute all-out tests.

Statistical analysis

Differences in parameter estimates between placebo and creatine trials were analyzed using Student's paired samples *t* tests. Comparisons between the CR and PL trials and the familiarization trial were made using one-way ANOVA with repeated measures. Statistical significance was accepted at $p < 0.05$ level and results are presented as mean ± standard deviation.

Results

The $\dot{V}O_2$ peak measured in the ramp incremental test was $4.01 \pm 0.36\,L \cdot min^{-1}$, with the GET occurring at $1.77 \pm 0.20\,L \cdot min^{-1}$ (~45% $\dot{V}O_2$ peak). The peak work rate attained in the incremental test was 374 ± 21 W and the work rate associated with the GET was 104 ± 18 W. The work rate associated with 50% of the interval between the GET and the $\dot{V}O_2$ peak (50% **Δ**) was calculated to be 230 ± 16 W.

The creatine supplementation period resulted in a significant increase in body mass, from 80.4 ± 9.2 kg at baseline to 81.6 ± 9.5 kg ($p < 0.05$). An increase in body mass was observed in all seven subjects, with the range of increase varying from 1.0% to 2.4% of pre-supplementation body mass. The body mass was not different from baseline after the placebo supplementation (80.3 ± 9.3 kg; $p > 0.05$).

In the first 3-minute all-out trial, which was performed in the absence of any dietary supplementation, the CP was 252 ± 25 W and the W′ was 18.9 ± 3.1 kJ. These parameter estimates were not different from those established in the subsequent PL and CR trials ($F_{2,6} = 0.5$, $p = 0.6$ for CP and $F_{2,6} = 0.2$, $p = 0.8$ for W′). There were no differences in the power profiles of the 3-minute all-out tests following placebo and creatine supplementation and this response was uniform across the group (Table; Figure 2). The CP estimated in the 3-minute all-out test was 252 ± 30 W in the PL trial and 255 ± 28 W in the CR trial ($p > 0.05$), and the W′ estimates were 19.4 ± 3.5 kJ in the PL trial and 19.2 ± 3.4 kJ in the CR trial ($p > 0.05$). The individual CP and W′ estimates following PL and CR supplementation are shown in the Table.

The peak power outputs measured during the all-out tests were not different between the two conditions (845 ± 117 W in PL and 859 ± 105 W in CR; $p > 0.05$) and these peak values were attained after 7 ± 1 seconds and 6 ± 1 seconds, respectively ($p > 0.05$). The total work done over 3 minutes of all-out cycling was 64.8 ± 4.9 kJ in the PL trial and 65.0 ± 4.9 kJ in the CR trial ($p > 0.05$).

Table. Individual work and power parameters measured in the 3-minute all-out test following 5 days of placebo or creatine supplementation

Subject	Placebo supplementation			Creatine supplementation		
	Peak P (W)	CP (W)	W′ (kJ)	Peak P (W)	CP (W)	W′ (kJ)
1	682	243	15.3	710	248	15.7
2	833	265	17.8	881	270	18.8
3	811	242	18.0	823	240	18.6
4	866	247	20.3	870	255	17.6
5	796	251	18.2	791	257	17.1
6	1073	306	19.5	1052	302	20.6
7	852	208	26.4	887	210	26.0
Mean ± SD	845 ± 117	252 ± 30	19.4 ± 3.5	859 ± 105	255 ± 28	19.2 ± 3.4

The Δ blood [lactate] values were 9.3 ± 1.3 mM in the PL trial and 8.7 ± 1.5 mM in the CR trial ($p > 0.05$).

Discussion

The principal original finding of this investigation was that a 5-day creatine loading intervention had no effect on the power-duration parameters as estimated by the novel "all-out critical power test". This result is in agreement with our first hypothesis that the CP would not be altered by creatine supplementation and confirms previous findings established using the conventional CP protocol and similar supplementation regimens (Miura et al. 1999; Smith et al. 1998). We also accept the second hypothesis which stated that the all-out test W′ parameter would not be affected by creatine loading, a finding which is in contrast to two previous reports of an enhanced W′ as estimated from the conventional constant-work-rate protocol (Miura et al. 1999; Smith et al. 1998). The present investigation is the first to report the influence of creatine loading on performance over a single bout of all-out exercise lasting 3 minutes. The total work done during 3 minutes of all-out cycling was unchanged after creatine loading, which extends previous reports of unaffected sprint performance during all-out cycling over shorter durations (e.g. Schneider et al. 1997).

In the present study, we used a supplementation regimen that was identical to previous investigations which reported a significant increase in muscle PCr (Finn et al. 2001; Casey et al. 1996; Hultman et al. 1996; Harris et al. 1992) and either an increase (Miura et al. 1999; Smith et al. 1998) or no statistically significant change in the conventional W′ (Eckerson et al. 2005). All seven participants showed an appreciable increase in body mass following creatine loading (mean increase of 1.2 kg), which is similar in magnitude to that which has previously been associated with increased muscle creatine uptake (Greenhaff et al. 1994). There was no indication from changes in body mass that any of the subjects were non-responders and the power profiles of PL and CR trials were indistinguishable in all seven cases (Figure 2).

The creatine loading intervention had no effect on the CP as estimated from the end-test power output achieved in the 3-minute all-out test. Although creatine loading is usually associated with enhancing the "anaerobic" component of exercise performance, there is some evidence that increased muscle PCr may delay fatigue during submaximal exercise by enhancing the so-called *neuromuscular fatigue threshold* (Smith et al. 2007; Stout et al. 2000). However, the relationship between the CP and the neuromuscular fatigue threshold is questionable (Pringle & Jones 2002), and it has been reported previously that creatine loading neither increases the CP (Miura et al. 1999; Smith et al. 1998) nor enhances submaximal time-trial performance (van Loon et al. 2003; Van Schuylenbergh et al. 2003). Any additional muscle PCr following creatine loading (~8–10 mM · kg^{-1} dry mass) (Finn et al. 2001; Casey et al. 1996) would be rapidly utilized following the start of the all-out sprint, and it is unlikely that increased PCr availability would alter the contribution of glycolytic metabolism or the accumulation of metabolites associated with the fatigue process sufficiently to induce a difference in power output after 2.5 minutes when the CP is estimated. This interpretation is supported by the similar Δ blood [lactate] values recorded in the two conditions.

Our finding that creatine supplementation did not alter the W′ as estimated from the 3-minute all-out test disagrees with two previous studies which used the conventional protocol and reported that W′ was increased by creatine loading (Miura et al. 1999; Smith et al. 1998). This disagreement might be interpreted to indicate either that the increased W′ reported previously was somehow inflated or that the novel all-out protocol was not sufficiently sensitive to detect a change in W′ caused by creatine loading. With regard to the first of these possibilities, earlier studies using the conventional protocol identified that the estimated W′ was increased by 10–26% with creatine loading (Miura et al. 1999; Smith et al. 1998), with another study reporting a non-significant 15% increase (Eckerson et al. 2005). Calculations regarding the likely consequences of creatine loading on muscle energetics during high-intensity exercise help to illuminate whether these increases are realistic. Short-term creatine loading has been shown to increase the muscle total creatine content by up to 20% (Harris et al. 1992), and, although the individual responses can vary considerably, this typically constitutes a ~10% increase in intramuscular PCr (Finn et al. 2001; Casey et al. 1996). The precise contribution of the energy yield from PCr hydrolysis to the magnitude of the W′ is difficult to quantify. However, Bangsbo et al. (1990) demonstrated that during ~3 minutes of exhaustive constant-work-rate exercise, the mean non-oxidative energy contribution was 45%, of which 15–20% was derived from PCr and other high-energy nucleotide stores, i.e. less than 9% of the total energy turnover could be attributed to PCr splitting. Therefore, irrespective of the protocol used, the magnitude of effect

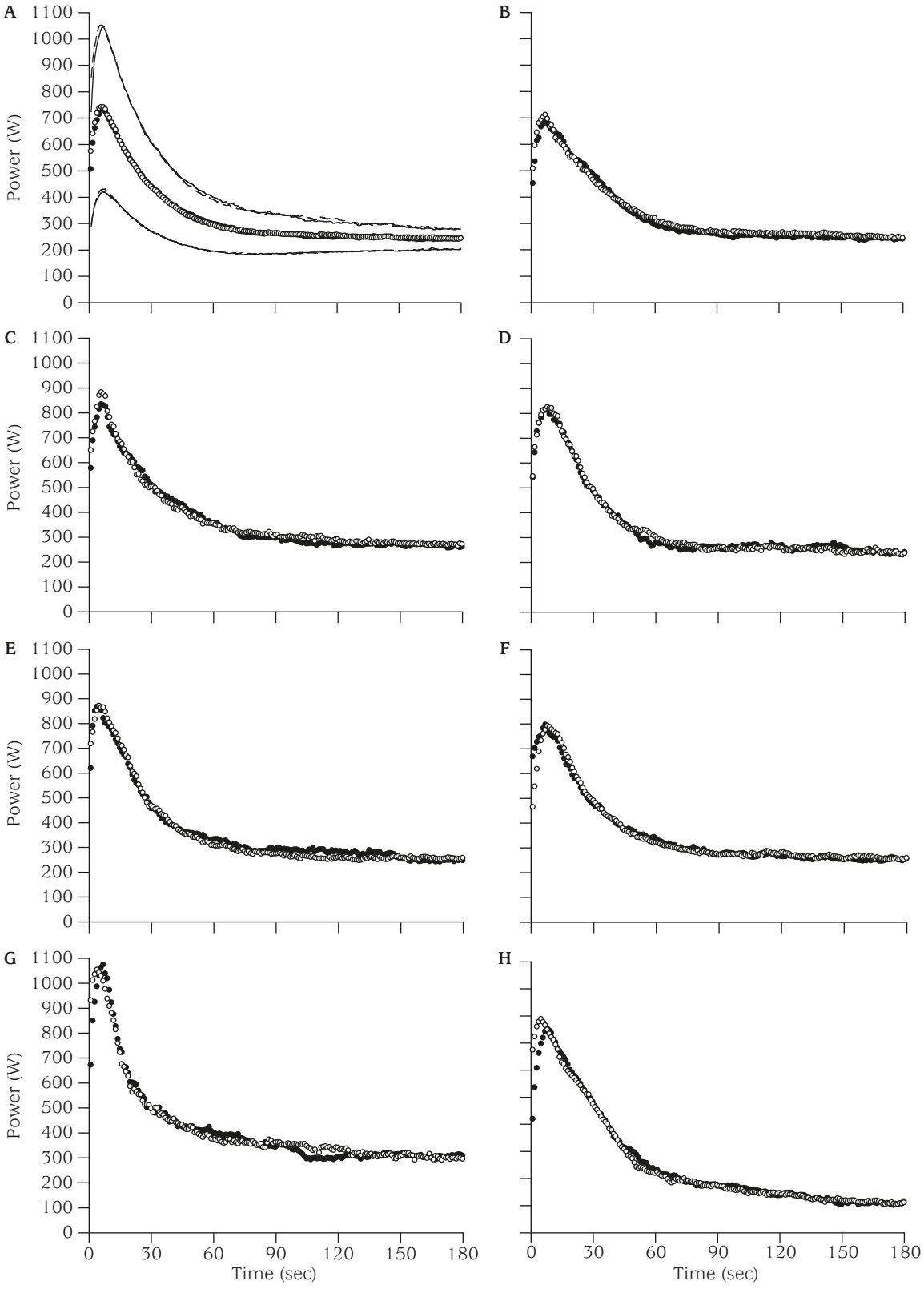

Fig. 2 The group mean (A) and the individual power profiles of the seven subjects (B–H) measured during the 3-minute all-out tests following a 5-day placebo (closed symbols) and creatine supplementation (open symbols). In (A), the solid lines indicate the ±SD associated with the PL trial and the dashed lines show the ±SD for the CR trial.

on the finite work capacity above CP induced by a ~10% increase in muscle PCr is likely to be relatively small.

With regard to the second of these possibilities, it can be broadly estimated that if the ~9% contribution to total energy turnover by PCr splitting was increased by ~10% as a result of creatine loading, the potential increase in the magnitude of the W′ (19.4 ± 3.5 kJ in the placebo trial) could be no more than 0.2 kJ (or ~1%), which is clearly beyond the accuracy of this test to detect. It should be pointed out, however, that this small increase would also be beyond the accuracy of the conventional protocol to detect. The accuracy of the conventional power-duration parameter estimates is dependent upon the number and duration of the prediction trials used in addition to the error associated with the mathematical model fit (Gaesser et al. 1995; Hill & Smith 1994; Hill 1993; Smith & Hill 1993). The all-out test parameters, in contrast, are not subject to mathematical modeling and are defined by the performance in a single all-out exercise test. The variation in the end-test power output of the 3-minute test (CP) between repeated trials (coefficient of variation [CV] of 3%; Burnley et al. 2006) is less than the variation observed in the conventionally estimated CP derived from repeated sets of prediction trials (CV ~6%; Smith & Hill 1993). Estimates of the W′ parameter are generally more variable, whether measured as the work done above end-test power in the all-out test (CV 9%; Vanhatalo 2008), or when established using prediction trials (CV ~10%; Gaesser & Wilson 1988). Confidence in the conventionally-measured W′ has been questioned due to the lack of stability shown both in the presence and absence of an intervention, as illustrated by a ~23% reduction in W′ reported in the control group of one training study (Jenkins & Quigley 1992), and individual responses varying from −19% to +32% in the experimental group of another training study (Poole et al. 1990). That such appreciable changes in W′ values tend not to attain statistical significance (Jenkins & Quigley 1992; Poole et al. 1990) may be an indication that the finite work capacity above CP is a multifactorial parameter, the determinants of which are difficult to isolate and control. This lack of stability of the conventional W′ estimates over time, along with fluctuation in individual performance over a 6-week creatine "wash-out" time (Miura et al. 1999), might have contributed to the significant 10–26% increases in W′ with creatine loading in two studies (Miura et al. 1999; Smith et al. 1998) and the non-significant 15% increase in another (Eckerson et al. 2005).

The physiological meaning of the presumably "anaerobic" W′ parameter of the power-duration relationship remains obscure due to the difficulty in quantifying the relative contribution from the oxygen-independent energy sources during dynamic high-intensity exercise. Recent evidence indicates that the W′ tends to be sensitive to interventions which influence the $\dot{V}O_2$ response dynamics, such as prior exercise and pacing (Jones et al. 2008b, 2003), and these findings may be difficult to explain if the determinants of the W′ were almost entirely anaerobic in nature. Subsequently, it has been proposed that exercise tolerance above CP, and by inference the magnitude of the W′, are defined by a number of factors including the capacity for anaerobic energy metabolism, the rate at which O_2 uptake increases at exercise onset, and the maximal rate of O_2 uptake that can be achieved (Burnley & Jones 2007). Although a close agreement between the all-out test and conventional W′ estimates has been reported (Vanhatalo et al. 2008a, 2007), the extent to which the factors which determine the magnitude of the W′ might vary between constant-work-rate and all-out exercise remains to be clarified. While, in a mechanical sense, the conventional and the all-out test W′ estimates both represent a fixed work capacity > CP (Vanhatalo et al. 2008b, 2007; Fukuba et al. 2003), it is evident that the temporal allocation of the W′ expenditure, and the associated depletion of muscle PCr and accumulation of fatigue-inducing metabolites, differ between the two "pacing modes". These differences potentially provide another explanation for the divergent results for the effects of creatine loading on W′ reported herein and elsewhere (Miura et al. 1999; Smith et al. 1998).

Creatine loading did not alter the total work done during the 3-minute all-out cycle test (64.8 ± 4.9 kJ in the PL trial and 65.0 ± 4.9 kJ in the CR trial). These results are consistent with several other studies which have reported that creatine ingestion is not ergogenic during all-out exercise of 10–60-second duration (Van Schuylenbergh et al. 2003; Finn et al. 2001; Schneider et al. 1997). However, despite the failure of creatine loading to measurably increase W′ or total work done in the all-out test, it should be noted that the potential impact of creatine supplementation would be proportionally greater for shorter sprint durations and may be more relevant during repeated efforts due to more rapid PCr resynthesis during recovery (van Loon et al. 2003; Balsom et al. 1995; Greenhaff et al. 1994; but see also Finn et al. 2001).

In conclusion, the parameters of the 3-minute all-out cycling test were unaltered after a 5-day creatine

loading intervention. This finding extends previous work by demonstrating that creatine loading (and the expected attendant increase in intramuscular [PCr]) does not influence the CP during all-out exercise. Our finding that W′ was not increased by creatine loading, however, is in contrast to two earlier studies (Miura et al. 1999; Smith et al. 1998), but is consistent with other reports that total work done is not altered during all-out exercise (Finn et al. 2001; Schneider et al. 1997). It is acknowledged that while the all-out test and conventional W′ estimates both theoretically represent a "finite work capacity above CP", their respective physiological determinants remain obscure and may express subtle differences (Vanhatalo et al. 2008a). However, consideration of the possible energetic consequences of a ~10% increase in muscle [PCr] with creatine loading indicate that the magnitude of the likely increase in W′ will be difficult to measure given a CV for W′ estimation of ~10% (Vanhatalo 2008; Gaesser & Wilson 1988). Therefore, although the [PCr] may be an important determinant of the W′ (Vanhatalo & Jones 2009; Ferguson et al. 2007; Heubert et al. 2005), the sensitivity of both conventional and all-out protocols may be insufficient to detect minor changes in the W′ consequent to relatively small increases in muscle PCr that can be achieved through dietary supplementation in healthy young individuals.

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