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Research article

RECOVERY OF POWER OUTPUT AND HEART RATE KINETICS DURING REPEATED BOUTS OF ROWING EXERCISE WITH DIFFERENT REST INTERVALS

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ABSTRACT
This study examined the effect of recovery time on the maintenance of power output and the heart rate response during repeated maximal rowing exercise. Nine male, junior rowers (age: 16 ± 1 years; body mass: 74.0 ± 9.1 kg; height: 1.78 ± 0.03 m) performed two consecutive all-out 1000 m bouts on a rowing ergometer on three separate occasions. The rest interval between the two bouts was 1.5 (INT1.5), 3 (INT3) and 6 min (INT6), allocated in random order. Power output was averaged for each 1000 m bout and for the first and last 500 m of each bout. Heart rate kinetics were determined using a two-component exponential model. Performance time and mean power output for the first bout was 209 ± 3 s and 313 ± 10 W respectively. Recovery of mean power output was incomplete even after 6 min (78 ± 2, 81 ± 2 and 84 ± 2 % for INT1.5, INT3 and INT6 respectively). Mean power output after INT6 was higher ($p < 0.01$) only compared with INT1.5. Power output during the first 500 m of bout 2 after INT6 was 10% higher compared with the second 500 m. During INT1.5 and INT3 power output during the first and the second 500 m of bout 2 was similar. Peak heart rate (~197 $b \cdot min^{-1}$) and the HR time constant (~13 s) were unaffected by prior exercise and recovery time. However, when the recovery was short (INT1.5), HR during the first 50 s of bout 2 was significantly higher compared with corresponding values during bout 1. The present study has shown that in order to maintain similar power outputs during repeated maximal rowing exercise, the recovery interval must be greater than 6 min. The influence of a longer recovery time (INT6) on maintenance of power output was only evident during the first half of the second 1000 m bout.

KEY WORDS: Interval training, maintenance of power output.

INTRODUCTION

Intense interval exercise is frequently used in rowing training during the competitive season (Secher, 1993). One type of interval training commonly used in rowing is “Speed training”. This type of training is recommended by the International Rowing Federation (Nielsen, 2001) for all categories during the competitive season and includes repeated bouts of high intensity exercise interspersed with short rest intervals. The main goal of speed training is that the work intensity is maintained approximately constant during each repetition. A variant of speed training in rowing involves repeated bouts of 1000 m at maximum intensity and is usually performed 2-3 times a week during the competitive season (Nielsen, 2001). Although this is a commonly used type of training, there is little information concerning recovery during rowing exercise (Koutedakis and Sharp, 1985). Usually, the length of the recovery between successive bouts of maximal rowing exercise is determined empirically by coaches who either use fixed work:recovery ratios (2:1, 1:1, 1:2) or use heart rate as an indirect index of recovery.

The two main metabolic processes that take place during the recovery period after a maximal bout of exercise are the restoration of phosphocreatine (PCr) stores and acid-base balance of the previously exercised muscles (Haseler et al, 1999, Laursen and Jenkins, 2002). These two processes proceed at different rates, with PCr resynthesis having a much faster half time (≈ 21-60 s) compared with that of muscle lactate and pH recovery (6-10 min Bogdanis et al., 1995, Haseler et al., 1999; Nevill et al., 1996). While much is known about the recovery of power output and muscle metabolism during repeated bouts of sprint exercise of short duration (<30 s; e.g. Bogdanis et al., 1995; 1996a; 1996b; Gastin, 2001), there is little information concerning repeated bouts of maximal effort exercise lasting around 3 min with varying rest intervals.

An interesting issue that may influence performance and recovery during rowing exercise is that it activates large muscle masses of both arms and legs. This may influence oxygen uptake kinetics and the heart rate (HR) response due to changes in hemodynamic parameters and the parasympathetic and sympathetic nervous system response (Hughson et al., 2000; Engelen et al., 1996). Heart rate kinetics have been examined during heavy arm or leg exercise and it has been found that both the heart rate time constant (HR τ) and oxygen uptake time constant $VO_2\tau$ are slower during arm exercise (Schneider et al., 2002). However, there is no information regarding HR kinetics during repeated bouts of exercise that combines arms and legs, as in rowing. Also, the effect of the length of recovery on heart rate kinetics during this type of exercise has not been examined previously.

Therefore, the first aim of the present study was to examine the effect of rest interval (time) between two consecutive bouts of maximal rowing exercise on the maintenance of power output. The second purpose of the study was to examine the effect of the recovery interval on heart rate response during repeated maximal rowing exercise.

METHODS

Subjects

Nine young male, national level rowers, mean (± SD) age 16 ± 1 years, volunteered to participate in this study. Their mean body mass and height were 74 ± 9 kg and 1.78 ± 0.03 m respectively. The training experience of the young rowers was 3 ± 1 years and at the time of the study they continued their normal training (5-6 times/week, for 1-2 hours). All volunteers were fully informed about the aim and the protocol of the study, which had the approval of the University of Athens Ethics Committee.

Experimental protocol

Each volunteer performed a preliminary familiarization 1000 m “all-out” test on a Concept II rowing ergometer, in order to determine the best performance time. After that, on separate occasions at least 3 days apart, each volunteer performed two consecutive “all-out” 1000 m bouts separated by different rest intervals in random order: a) 1.5 min (INT1.5), b) 3 min (INT3), and c) 6 min (INT6). During the rest interval the volunteers remained seated on the rowing ergometer. The drag factor used throughout all the efforts was set at 120, which is recommended for the age of the volunteers according to the FISA (Fédération Internationale des Sociétés d'Aviron) indoor rowing training guide 2004. All participants were instructed to maintain their normal nutritional habits and abstain from intensive exercise 24 h prior to each testing session.

Measurements and data analysis

All measurements were performed on a Concept II rowing ergometer, interfaced with a computer. Power output (W) and heart rate (HR) were recorded stroke-by-stroke using the e-row software. Peak power output was defined as the highest power output generated during a single stroke. Mean power output was calculated for the each rowing bout (1000 m), as well as for the first and last 500 m of each bout.

In order to compare the HR responses after different recovery intervals of maximal rowing exercise, HR kinetics parameters were calculated during each of the two bouts on all occasions. The stroke-by-stroke HR data obtained by the e-row software during each bout were linearly interpolated to 1-s values and fitted using a two component exponential model (OriginPro v. 7.5, OriginLab Corporation):

$$HR(t) = Baseline + A_1 \cdot (1 - e^{-(t-TD_1)/\tau_1}) + A_2 \cdot (1 - e^{-(t-TD_2)/\tau_2})$$

where “Baseline” is the HR just before the onset of the exercise, A is the amplitude, τ is the time constant and TD is the time delay. The model parameters were determined by least-squares nonlinear regression in which the best fit was defined by minimization of the residual sum of *squares.* A_1, τ_1 *and* TD_1 *describe the HR fast component, while* A_2, τ_2 *and* TD_2 *describe the HR slow component.*

Statistical analysis

Differences in model parameters, performance time, power output and HR between INT6, INT3 and INT1.5 were tested using a two – way ANOVA with repeated measures on both factors (bout and rest interval). Significance was set at $p < 0.05$. Results are presented as mean ± standard error.

RESULTS

There was no significant difference in any of the parameters measured between the first 1000 m bouts on the 3 different occasions (mean power: 315 ± 11, 311 ± 11, 314 ± 10 W; performance time: 209 ± 3, 210 ± 3, 208 ± 3 s for INT1.5, INT3 and INT6, respectively).

Figure 1 shows the time course of power output per stroke for a typical volunteer of the present study. During each rowing bout, power output peaked during the first few strokes and then declined. [Note the tendency of power output to stabilize and/or increase during the last quarter of the each bout (Figure 1)].

Peak power output during bout 1 averaged 415 ± 20 W. There was no recovery of peak power output even after the longest rest interval and also no significant difference between the percent restoration of peak power on all occasions (INT1.5: 84 ± 3, INT3: 84 ± 3 and INT6: 88% ± 4%)

Recovery of mean power output during bout 2 was also incomplete and reached 78 ± 2, 81 ± 2 and 84 ± 2 % of bout 1 for INT1.5, INT3 and INT6, respectively (Figure 2). Mean power output during the second bout of INT6 was significantly higher compared with the corresponding bout during INT1.5 ($p < 0.01$; Figure 2). Accordingly, performance time was 5 ± 1 s better after INT6 compared with INT1.5 (223 ± 3 *vs.* 228 ± 3 s; $p < 0.01$).

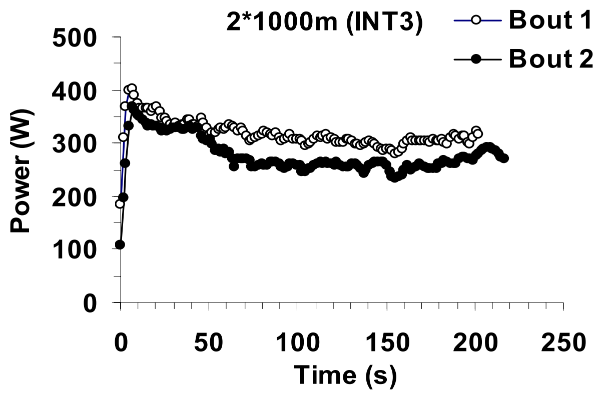

Figure 1. A typical example of the time course of power output during two 1000 m bouts separated by a rest interval of 3 min (individual data from a representative volunteer).

Figure 3 shows the mean power output during the first and the second 500 m of bout 1 and bout 2 during the three conditions. Power output during the second 500 m of bout 1 was lower compared with the first 500 m on all 3 occasions (90 ± 3 % of bout 1; Figure 3). Power output during the first 500 m of bout 2 was significantly higher (~10%) compared with the second 500 m - but only during INT6 (Figure 3). During INT1.5 and INT3, power output during the first and the second 500 m of bout 2 was similar. It is noteworthy that during bout 2, power output during the second 500 m (500-1000 m) was

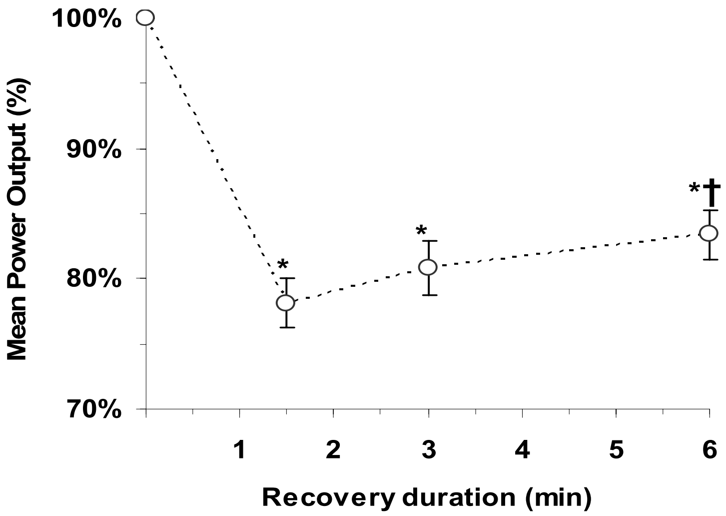

Figure 2. Recovery of mean power output during two 1000 m bouts of rowing exercise separated by 3 different recovery intervals. Results are presented as a percentage of power output during bout 1. * denotes $p < 0.01$ compared with bout 1, † denotes $p < 0.01$ compared with bout 2 after 1.5 min recovery.

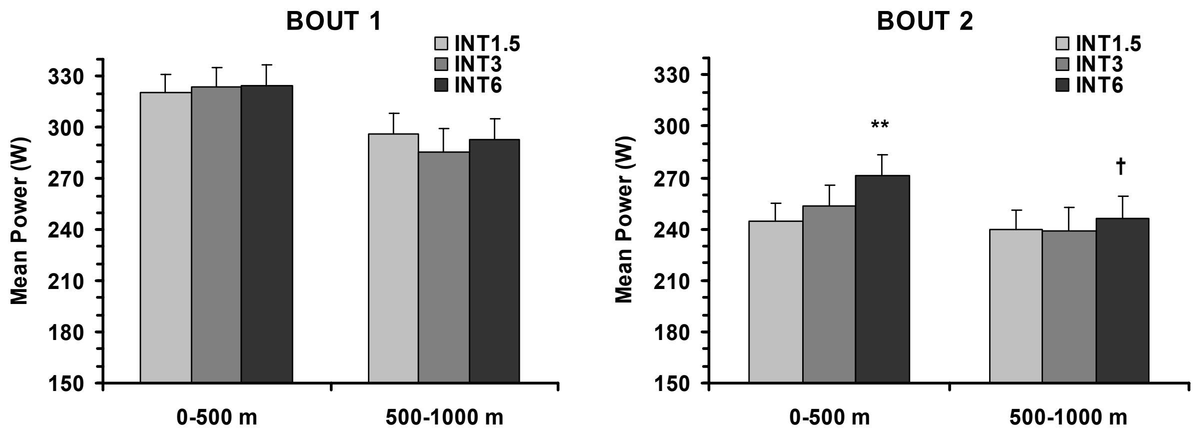

Figure 3. Mean power output during the first and the second 500 m of bout 1 and bout 2 during the three interval conditions. ** denotes $p < 0.01$ compared with INT1.5 and INT3 and † denotes $p < 0.01$ compared with 0-500 m of the corresponding interval in bout 2 (INT6).

similar after all rest intervals (Figure 3). Therefore, the higher mean power output in bout 2 after INT6 (compared with INT1.5 and INT3) (Figure 2) was due to a higher power output occurring during the first 500 m.

Mean and peak heart rate during each exercise bout are shown in Table 1. No significant differences were found in peak heart rate between all exercise bouts. However, the mean HR of bout 2 during INT1.5 was higher compared with bout 1 (Table 1).

Comparison of the HR kinetics parameters between INT1.5, INT3 and INT6 showed that, although the time constant of the primary component ($\tau 1$) did not significantly change from bout 1 to bout 2 after all recovery intervals, the amplitude (A1) of the primary component showed a significant decrease and the baseline heart rate exhibited a significant increase (Table 2). In bout 2, when the recovery was short (INT1.5), HR during the first 50 s of exercise was significantly higher compared with the corresponding values of bout 1, while this was not evident after INT6 (Figure 4).

DISCUSSION

The main findings of this study were: a) that recovery of performance time and mean power output during two repeated maximal bouts of rowing exercise was incomplete even after 6 min, b) that the benefit of the longer rest interval was apparent only during the first 500 m of bout 2 and c) the HR time constant was unaffected by prior exercise and recovery time. However, when the recovery was short (INT1.5), HR during the first 50 s of bout 2 was significantly higher compared with the corresponding values of bout 1.

The extent to which prior exercise can enhance or impair performance during subsequent supramaximal exercise is dependent on the extent to which acid-base balance and/ or muscle metabolic factors are altered (Wilkerson et al., 2004). For example, the time to exhaustion during supramaximal exercise (105% VO_2peak) was reduced by ~ 19% when it was preceded by 3 bouts of 30 s maximal sprint cycling and 15 min of recovery (blood [lactate] ~7.7 mmol·L^{-1} before the onset of supramaximal exercise). On the contrary, when the "priming" exercise involved 6 min of constant work-rate cycling at 80% VO_2peak, that was followed by 10 min recovery (blood [lactate] ~2.6 mmol·L^{-1} before the onset of supramaximal exercise), the time to exhaustion during subsequent supramaximal exercise was significantly extended (Jones et al., 2003).

Although rowing exercise is fuelled mainly by aerobic metabolism (Secher, 1993), there is a considerable involvement of anaerobic pathways as indicated by blood lactate concentrations that reach as high as 19 mmol·L^{-1} after 2000 m of maximal rowing (Secher, 1993). Unfortunately, changes in muscle metabolites have not been reported for

Table 1. Mean and peak heart rate (HR) during the 3 different interval sessions. Data are means (±SE).

	INT1.5		INT3		INT6	
	Bout 1	Bout 2	Bout 1	Bout 2	Bout 1	Bout 2
Mean HR (b·min^{-1})	181 (2)	185 (3)**	182 (2)	184 (2)	183 (2)	183 (1)
Peak HR (b·min^{-1})	195 (1)	198 (3)	196 (2)	197 (2)	197 (2)	196 (2)

** $p < 0.01$ compared with bout 1.

Table 2. HR kinetics parameters during two repeated 1000 m bouts on the rowing ergometer, separated by 1.5 min (INT1.5), 3 min (INT3) and 6 min (INT6). Baseline: HR before the start of each bout; A1: amplitude and τ1: time constant of the primary component, respectively. Data are means (SE).

	Bout	Baseline ($b \cdot min^{-1}$)	A1 ($b \cdot min^{-1}$)	τ1 (s)
INT1.5	**1**	106 (6)	78 (6)	12.6 (0.5)
	2	143 (7)*	46 (6)*	11.8 (1.2)
INT3	**1**	105 (9)	79 (7)	12.9 (0.9)
	2	131 (5)*	58 (4)*	14.6 (1.6)
INT6	**1**	105 (8)	81 (7)	13.3 (1.0)
	2	125 (3)*	62 (4)*	16.9 (1.5)

* $p < 0.05$ compared with bout 1.

rowing exercise but there is evidence that the relatively long duration of exercise at an intensity close to maximal oxygen uptake will lower phosphocreatine (PCr) stores and increase muscle lactate levels (Ren et al, 1988; Sahlin et al. 1987). Thus, it is possible that increased muscle lactate and reduced phosphocreatine stores may influence recovery of power output even for this type of exercise, in a similar manner as reported for shorter duration (30 s) maximal sprint exercise (Bogdanis et al., 1995; 1996b). In these studies complete recovery did not take place even after 6 min of rest and this was mainly due to a slow PCr resynthesis and muscle pH recovery (Bogdanis et al., 1996b; Nevill et al., 1996).

The importance of PCr resynthesis and muscle lactate removal for repeated rowing exercise is also indicated by the differential recovery of the first and second 500 m of bout 2. As can be seen in Figure 3, power output during the first 500 m of bout 2 was higher during INT6 compared with INT1.5 and INT3 - and it was also 10% higher compared with the second 500 m in the same condition (500-1000 m). During INT1.5 and INT3 power output during the first and the second 500 m of bout 2 was similar. This shows that the influence of the longer recovery time was only evident during the first 500 m of bout 2; and may indicate a more complete PCr resynthesis and more efficient lactate removal following INT6 (Bogdanis et al., 1995; Haseler et al., 1999). This would allow a greater contribution of anaerobic metabolism during the initial part of the second 1000 m bout, thus enabling generation of higher power outputs (Bangsbo, 1998; Medbo and Tabata, 1993). The fact that there were no significant differences in power output during the second 500 m after all rest intervals may be due to a low anaerobic contribution during that part of the bout and an almost complete activation of aerobic metabolism (Billat, 2001). Previous studies using high intensity cycling or rowing exercise have shown that maximal oxygen uptake is reached during the second to third minute of exercise (Astrand and Rodahl, 1986; Medbo and Tabata, 1993; Secher, 1993).

Prior heavy exercise may result in a significantly higher heart rate and oxygen uptake during the second bout (Burnley et al., 2002; Endo et al., 2004; Scheuermann et al., 2002). In the present study the heart rate response during the second bout was influenced only when recovery was short (INT1.5). In this case the mean heart rate during the first 50 s was higher, but the peak heart rate and the time constant of the fast component remained unchanged during all exercise bouts. Similar findings for an unchanged HR time constant have been reported by Scheuermann et al. (2002) and also by Zavorsky et al. (1998), who reported that VO_2 and heart rate were independent of recovery duration (60, 120 or 180 s), the latter study using repeated bouts of short, intense exercise (10 x 400 m).

There is evidence that the correlation between the VO_2 τ and HR τ depends on the mode of exercise (Schneider et al., 2002) and that the correlation is stronger during leg versus arm exercise. If the HR response in the present study is taken to reflect the VO_2 response, then the aerobic contribution to energy supply during the initial part of the second bout was probably higher when the rest interval was short (INT1.5). However, this possibly higher aerobic contribution was not adequate to balance the greatly depressed anaerobic contribution in that condition as indicated by the power output data (Figure 3). Alternatively, another explanation for the higher heart rate during the first 50 s may be the higher catecholamine levels before exercise that was preceded by a relatively short rest interval (Engelen et al., 1996).

The HR τ values reported in the present study are significantly faster compared with other studies (Schneider et al, 2002). Schneider et al. (2002) reported HR τ values of 74.7 ± 4.4 s for arm cranking and 55.6 ± 3.5 s for leg cycling whereas in the study of Scheuermann et al. (2002), HR τ was

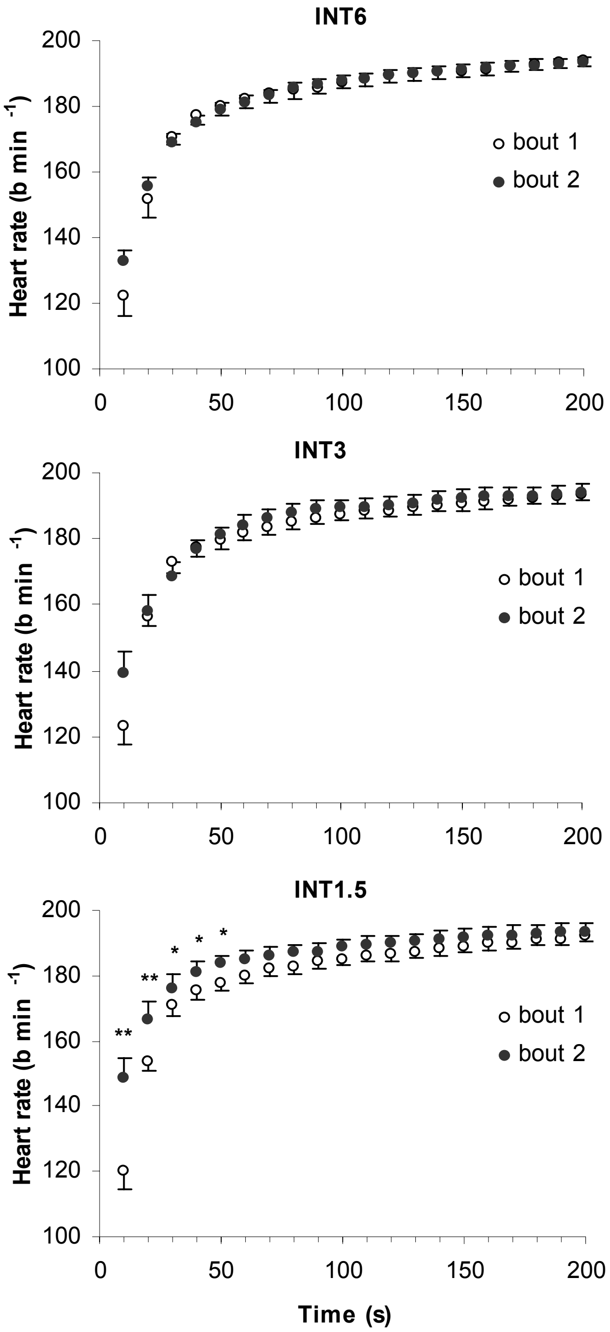

Figure 4. Heart rate responses during two bouts of maximal rowing exercise with three different recovery intervals (INT1.5, INT3 and INT6). For clarity, data are presented as 10-s averages. * $p < 0.05$ and ** $p < 0.01$ compared with corresponding time values of bout 1.

21.5 ± 4.0 s after the first bout of heavy exercise and 23.7 ± 0.8 s after the second bout of moderate exercise intensity. Moreover, in the study of Gurd et al (2005), the HR τ varied between 31.9 ± 16.5 and 37.5 ± 17.5 s after the first and the second bout of heavy and moderate exercise, respectively. The much faster HR τ values reported in our study (Table 2) may be due to the nature of rowing exercise that combines the use of arms and legs. Alternatively, these differences may be attributed to the different exercise intensity and also to differences in age and training status of the volunteers.

CONCLUSIONS

The present study has shown that recovery of power output during repeated maximal bouts of rowing exercise was incomplete, even after 6 min rest. During the second bout, the positive effect of INT6 was evident only during the first 500 m, while there was no effect of recovery time on power output during the second 500 m. The HR response during the second bout of maximal exercise was influenced only when the recovery interval was short. During INT1.5 the mean heart rate during the first 50 s was higher, but the peak heart rate and the time constant of the fast component were unaffected by the length of recovery and prior exercise. Based on our results practical advice for rowing coaches may be that in order to maintain similar power outputs during 1000 m repeats, the recovery interval must be greater than 6 min or the ratio of interval-to-exercise must be greater than 2 to 1.

REFERENCES

Astrand, P-O. and Rodahl, K. (1986) *Textbook of work physiology*. 3rd edition. McGraw-Hill, New York. 302.

Bangsbo, J., (1998) Quantification of anaerobic energy production during intense exercise. *Medicine and Science in Sports and Exercise* **30,** 47-52.

Billat, L.V. (2001) Interval training for performance: a scientific and empirical practice. *Sports Medicine* **31**, 13-31.

Bogdanis, G.C., Nevill, M.E., Boobis, L.H., Lakomy, H.K. and Nevill, A.M. (1995) Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *Journal of Physiology* **482**(Pt 2), 467-480.

Bogdanis, G.C., Nevill, M.E., Lakomy, H.K., Graham, C.M. and Louis G. (1996a) Effects of active recovery on power output during repeated maximal sprint cycling. *European Journal of Applied Physiology* **74**, 461-469.

Bogdanis, G.C., Nevill, M.E., Boobis, L.H., and Lakomy, H.K. (1996b) Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. *Journal of Applied Physiology* **80**, 876-884.

Burnley, M., Doust, J.H., Ball, D. and Jones, A.M. (2002) Effects of prior heavy exercise on VO_2 kinetics during heavy exercise are related to changes in muscle activity. *Journal of Applied Physiology* **93**, 167-174.

Endo, M., Usui, S., Fukuoka, Y., Miura, A., Rossiter, H.B. and Fukuba, Y. (2004) Effects of priming exercise intensity on the dynamic linearity of the pulmonary VO_2 response during heavy exercise. *European Journal of Applied Physiology* **91**, 545-554.

Engelen, M., Porszasz, J., Riley, M., Wasserman, K., Maehara, K. and Barstow, T.J. (1996) Effects of hypoxic hypoxia on O_2 uptake and heart rate kinetics during heavy exercise. *Journal of Applied Physiology* **81**, 2500-2508.

Gastin, P.B. (2001) Energy system interaction and relative contribution during maximal exercise. *Sports Medicine* **31**, 725-741.

Gurd, B.J., Scheuermann, B.W., Peterson, D.H. and Kowalchuk, J.M. (2005) Prior heavy-intensity exercise speeds VO_2 kinetics during moderate-intensity exercise in young adults. *Journal of Applied Physiology* **98**, 1371-1378.

Haseler, L.J., Hogan, M.C. and Ritsardson, R.S. (1999) Skeletal muscle phosphocreatine recovery in exercise-trained humans is dependent on O_2 availability. *Journal of Applied Physiology* **86**, 2013-2018.

Hughson, R.L., O'Leary, D.D., Betik, A.C. and Hebestreit, H. (2000) Kinetics of oxygen uptake at the onset of exercise near or above peak oxygen uptake. *Journal of Applied Physiology* **88**, 1812-1819.

Jones, A.M., Wilkerson, D.P., Burnley, M. and Koppo, K. (2003). Prior heavy exercise enhances performance during subsequent perimaximal exercise. *Medicine and Science in Sports and Exercise* **35**, 2085-92.

Koutedakis, Y. and Sharp, N.C. (1985) Lactic acid removal and heart rate frequencies during recovery after strenuous exercise. *British Journal of Sports Medicine* **19**, 199-202.

Laursen, P.B. and Jenkins, D.J. (2002) The scientific basis for high-intensity interval training. *Sports Medicine* **32**, 53-73.

Medbo, J.I. and Tabata, I. (1993) Anaerobic energy release in working muscle during 30 s to 3 min of exhausting bicycling. *Journal of Applied Physiology* **75**, 1654-1660.

Nevill, M.E., Bogdanis, G.C., Boobis, L.H., Lakomy, H.K.A. and Williams, C. (1996) Muscle metabolism and performance during sprinting. In: *Biochemistry of Exercise IX.* Eds: Maughan, R.J. and Shirreffs, S.M. Human Kinetics Publishers. 243-259.

Nielsen, T.S. (2001) Basic Rowing Physiology. In: *FISA Handbook-Level 1*. FISA

Ren, J.M., Henriksson, J., Katz, A. and Sahlin, K. (1988) NADH content in type I and type II muscle fibres after dynamic exercise. *Biochemical Journal* **251**, 183-187.

Sahlin, K., Katz, A. and Henriksson, J. (1987) Redox state and lactate accumulation in human skeletal muscle during dynamic exercise. *Biochemical Journal* **245**, 551-556.

Scheuermann, B.W. and Barstow, T.J. (2003) O_2 uptake kinetics during exercise at peak O_2 uptake. *Journal of Applied Physiology* **95**, 2014-2022.

Scheuermann, B.W., Bell, C., Paterson, D.H., Barstow, T.J. and Kowalchuk, J.M. (2002) Oxygen uptake kinetics for moderate exercise are speeded in older humans by prior heavy exercise. *Journal of Applied Physiology* **92**, 609-616.

Schneider, D.A., Wing, A.N. and Morris, N.R. (2002) Oxygen uptake and heart rate kinetics during heavy exercise: a comparison between arm cranking and leg cycling. *European Journal of Applied Physiology* **88**, 100-106.

Secher, N.H. (1993) Physiological and biomechanical aspects of rowing. *Sports Medicine* **15**, 24-42.

Weston, A.R., Myburgh, K.H., Lindsay, F.H., Dennis, S.C., Noakes, T.D. and Hawley, J.A. (1997) Skeletal muscle buffering capacity and endurance performance after high-intensity interval training by well-trained cyclists. *European Journal of Applied Physiology* **75**, 7-13.

Wilkerson, D.P., Koppo, K. and Jones, A.M. (2004) Effect of prior multiple-sprint exercise on pulmonary O_2 uptake kinetics following the onset of perimaximal exercise. *Journal of Applied Physiology* **97**, 1227-1236.

Zavorsky, G.S., Montgomery, D.L. and Pearsall, D.J. (1998) Effect of intense interval workouts on running economy using three recovery durations. *European Journal of Applied Physiology* **77**, 224-230.

KEY POINTS

- The recovery of mean power output during two repeated maximal 1000 m bouts of rowing exercise was incomplete even after a 6 min rest interval.
- The benefit of the longer rest interval was apparent only during the first 500 m of bout 2.
- The HR time constant was unaffected by prior exercise and the time of recovery. However, when the recovery was short, HR during the first 50 s of bout 2 was significantly higher compared with the corresponding values of bout 1.

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