

## Accepted Manuscript

Title: Oxygen uptake during repeated-sprint exercise

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PII: S1440-2440(14)00030-9

DOI: <http://dx.doi.org/doi:10.1016/j.jsams.2014.02.002>

Reference: JSAMS 995



To appear in: *Journal of Science and Medicine in Sport*

Received date: 5-9-2013

Revised date: 10-12-2013

Accepted date: 1-2-2014

Please cite this article as: McGawley K, Bishop DJ, Oxygen uptake during repeated-sprint exercise, *Journal of Science and Medicine in Sport* (2014), <http://dx.doi.org/10.1016/j.jsams.2014.02.002>

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**Oxygen uptake during repeated-sprint exercise**

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## Oxygen uptake during repeated-sprint exercise

### Abstract

**Objectives:** Repeated-sprint ability appears to be influenced by oxidative metabolism, with reductions in fatigue and improved sprint times related to markers of aerobic fitness. The aim of the current study was to measure the oxygen uptake ( $\dot{V}O_2$ ) during the first and last sprints during two, 5 x 6-s repeated-sprint bouts. **Design:** Cross-sectional study. **Methods:** Eight female soccer players performed two, consecutive, 5 x 6-s maximal sprint bouts (B1 and B2) on five separate occasions, in order to identify the minimum time ( $t_{rec}$ ) required to recover total work done ( $W_{tot}$ ) in B1. On a sixth occasion, expired air was collected during the first and last sprint of B1 and B2, which were separated by  $t_{rec}$ . **Results:** The  $t_{rec}$  was  $10.9 \pm 1.1$  min. The  $\dot{V}O_2$  during the first sprint ( $\sim 10\%$ ) was significantly less than the last sprint ( $\sim 40\%$ ) in each bout ( $p < 0.001$ ), and the estimated aerobic contribution to the final sprint (measured in kJ) was significantly related to  $\dot{V}O_{2max}$  in both B1 ( $r = 0.81$ ,  $p = 0.015$ ) and B2 ( $r = 0.93$ ,  $p = 0.001$ ). In addition, the  $\dot{V}O_2$  attained in the final sprint was not significantly different from  $\dot{V}O_{2max}$  in B1 ( $p = 0.284$ ) or B2 ( $p = 0.448$ ). **Conclusions:** The current study shows that the  $\dot{V}O_2$  increases from the first to the last of 5 x 6-s sprints and that  $\dot{V}O_{2max}$  may be a limiting factor to performance in latter sprints. Increasing  $\dot{V}O_{2max}$  in team-sport athletes may enable increased aerobic energy delivery, and consequently work done, during a bout of repeated sprints.

**Keywords:** repeated-sprint ability; team sports; aerobic contribution; accumulated oxygen deficit; soccer; football

## Introduction

Intense physical efforts performed at maximal or near-maximal speeds are important determinants of successful team-sport performance, with more fast-paced running and sprinting completed by top-level soccer players (both male and female) compared with their lower-level counterparts.<sup>1,2</sup> However, the volume of high-intensity running (measured by distance covered) has been shown to decline over the course of a soccer match, irrespective of playing standard.<sup>1</sup> These findings reflect fatigue development and suggest that the ability to recover from high-intensity running and sprinting may be an important marker of successful physical performance within team sports. It has also been suggested that fatigue development following high-intensity bursts has a detrimental effect on technical performance, and that technical success may be related to the ability to recover.<sup>3</sup>

Various markers of aerobic fitness, including maximal oxygen uptake ( $\dot{V}O_{2\max}$ ), velocity at  $\dot{V}O_{2\max}$  ( $v\text{-}\dot{V}O_{2\max}$ ), velocity at the onset of blood lactate accumulation ( $v\text{-}OBLA$ ) and  $\dot{V}O_2$  kinetics, have been related to a reduction in fatigue (i.e., a smaller decrement in performance) over the course of a repeated-sprint bout.<sup>4-6</sup> As well as performance decrement, other parameters associated with repeated-sprint ability (RSA) have been related to markers of aerobic fitness. For example, da Silva et al.<sup>6</sup> found both  $v\text{-}OBLA$  and  $v\text{-}\dot{V}O_{2\max}$  to be negatively correlated with the mean time to complete 7 x 34.2-m sprints. In addition, Dupont et al.<sup>5</sup> reported a positive correlation between the time constant for the fast component of  $\dot{V}O_2$  kinetics and the total time to complete 15 x 40-m sprints. Therefore, it appears that RSA is at least partially influenced by oxidative metabolism, perhaps via improved PCr resynthesis between sprints and greater aerobic contributions to latter sprints.<sup>7,8</sup> Despite these relationships, the  $\dot{V}O_2$  during isolated maximal sprints has not been investigated during repeated-sprint exercise.

The majority of studies reporting aerobic contributions to maximal exercise have used single sprints lasting more than 10 s, with reported estimates for 90-, 60-, 45- and 30-s sprints of 61 – 64%, 49%,

31% and 23 – 28%, respectively.<sup>9,10</sup> These data demonstrate a linear decrease in aerobic contribution as sprint time decreases and, using these values, the predicted aerobic contribution to a 6-s sprint would be ~ 9%. Péronnet and Thibault<sup>11</sup> calculated a value slightly lower than this estimate, suggesting a 5% aerobic contribution to a single 6-s sprint. However, this 5% value was derived from a mathematical model of metabolic energy production for the 1987 men's 60-m world record, rather than measured directly. Relatively few studies have attempted to unravel the complex energy contributions to repeated sprints lasting < 10 s. Gaitanos et al.<sup>12</sup> showed a 65% decrease in anaerobic ATP production from the first to the last of 10 x 6-s sprints separated by 30 s. Since the associated performance decline was much smaller (27%), the authors hypothesised an increased aerobic energy contribution to the latter sprints. However, this was not measured directly and the hypothesis does not appear to have been tested to date.

The aim of the current study was to measure the  $\dot{V}O_2$  and estimate the aerobic contribution during the first and last sprints of two, 5 x 6-s repeated-sprint bouts. It was hypothesised that i) the  $\dot{V}O_2$  and estimated aerobic contribution would be greater during the final sprint versus the first sprint of each respective bout and ii) the estimated aerobic contribution to the final sprint of each bout would be related to  $\dot{V}O_{2max}$ .

## Methods

Eight female soccer players (mean  $\pm$  SD: age, 26.7  $\pm$  7.4 y; body mass, 60.9  $\pm$  6.0 kg) volunteered to participate in this study. All participants were competing in the women's national soccer league and were training regularly throughout the testing period, which coincided with the competitive season. Participants were informed of all procedures, requirements, benefits and risks relating to the study before providing written informed consent and commencing any experimental tests. Ethical clearance for testing procedures was received from the University of Western Australia ethics committee.

Participants were familiarised with the testing equipment and protocols before completing seven experimental testing sessions. The first session involved a graded-exercise test to exhaustion (GXT) to determine the lactate threshold (LT) and  $\dot{V}O_{2\max}$ . In the subsequent five sessions participants completed two, consecutive, 5 x 6-s maximal sprint bouts (B1 and B2) separated by a range of passive recovery periods lasting between 5 and 14 min to identify the shortest time ( $t_{\text{rec}}$ ) required for each individual to recover RSA, measured as total work done ( $W_{\text{tot}}$ ) in B1. In the final testing session expired air was collected during the first and fifth sprints of both B1 and B2, which were separated by a passive recovery period equal in duration to  $t_{\text{rec}}$ . The second repeated-sprint bout was performed after  $t_{\text{rec}}$  to ensure that residual fatigue did not influence the  $\dot{V}O_2$  measures.

The GXT was completed on an air-braked, track-cycle ergometer (Evolution Pty. Ltd., Australia) and commenced at a power output of 50 – 100 W, based on estimates during the familiarisation sessions. Each stage involved a 4-min work period followed by a 1-min rest period and power output increased by 25 W per stage. Verbal feedback was provided throughout the test with strong verbal encouragement provided during the latter stages. The test was terminated at volitional exhaustion or when the required power output could no longer be sustained. Expired air was collected using a turbine ventilometer (Morgan, 225A, England) and was continuously analysed for  $O_2$  and  $CO_2$  using Ametek gas analysers (Applied Electrochemistry, SOV S-3A11 and COV CD-3A, USA). Ventilatory parameters were displayed on an IBM computer system allowing  $\dot{V}O_2$  to be monitored at 15-s intervals for the duration of the test. The sum of the four highest consecutive 15-s  $\dot{V}O_2$  values gave the  $\dot{V}O_{2\max}$ . Blood samples were collected from the earlobe during the rest period between each incremental stage and blood lactate concentration ( $[La^-]_{\text{bl}}$ ) was analysed immediately (ABL<sup>TM</sup> 625, Radiometer, Denmark). The LT was identified by the point on the polynomial regression curve (power output versus  $[La^-]_{\text{bl}}$ ) yielding the maximal perpendicular distance to the straight line connecting the first increase in lactate above resting level and the final lactate point.<sup>13</sup>

Sprints were performed on a modified, wind-braked, front-access, cycle ergometer (Model Ex-10, Repco, Australia) from a stationary, standing position and participants remained out of the seat throughout each maximal effort. Pedals were fitted with standard toe clips and a strong nylon heel strap. Two repeated-sprint familiarisation trials were prescribed prior to the main trials in accordance with previous research.<sup>14</sup> All trials were performed at the same time of day ( $\pm 2$  h) to overcome any influence of circadian variance<sup>15</sup> and no intense training was performed in the 24 h that preceded testing. The main trials were completed within six weeks for all participants.

Each main trial commenced with a warm-up of 5 min cycling at 80 W, followed by three practice sprint starts. Following the practice starts, and 90 s of passive rest, participants produced one, maximal, 6-s benchmark sprint. The benchmark sprint was followed by 5 min of passive recovery before participants completed B1. To prevent pacing effects, the work produced during sprint 1 of B1 was required to equal or exceed 95% of the work done during the benchmark sprint. If this criterion was not achieved, participants were required to rest for a further 5 min and restart B1 (this occurred on only two occasions out of 40 trials). During all maximal sprints, participants received strong verbal encouragement and clear instructions of when to stop sprinting, as well as continuous feedback during the active recovery periods to ensure that they recovered at the correct intensity and were in the stationary, ready position 3 s prior to the start of each sprint. The five sprints within each repeated-sprint bout were separated by 24 s of low-intensity cycling at 75% LT.

For the first five main trials, B1 and B2 were separated by passive recovery periods that were selected to determine the minimum time required to recover RSA. Performance was deemed to have recovered during B2 if  $W_{\text{tot}}$  exceeded 98% of the value measured during B1. The first trial used a recovery period lasting 5 min, after which the duration was modified gradually up or down over the next four trials to identify the shortest possible individual estimates of  $t_{\text{rec}}$ . In a sixth main trial, B1 and B2 were separated by  $t_{\text{rec}}$  and expired air was collected during the first and last sprints of each bout (i.e., S1, S5, S6 and S10) for the 6-s sprint periods using Douglas bags. The Douglas bags were 20 L in volume and were connected directly to the Hans Rudolph mouthpiece, which removed the issue of dead space

resulting from connective tubing. The same set up was used for the first and last sprints of each bout so that any dead space from the mouthpiece itself (albeit small) would be constant. Mean power output (MP) and peak power output (PP) were recorded during each of the sprints. The decrement in PP ( $PP_{dec}$ ) and work done ( $W_{dec}$ ) over the six sprints within each bout were calculated using the formula for sprint decrement reported previously.<sup>16</sup>

The total energy requirements for S1, S5, S6 and S10 were estimated from the MP achieved during each of the sprints using the linear relationship between power output (W) and energy expenditure ( $\text{kJ}\cdot\text{min}^{-1}$ ) obtained from the sub-LT portion of the GXT (Figure 1). Total aerobic energy expenditure for each of the sub-LT stages of the GXT was calculated by multiplying  $\dot{V}O_2$  by the energy equivalent per litre of oxygen at the given steady-state respiratory quotient (RQ),<sup>17</sup> then converting  $\text{kcal}\cdot\text{min}^{-1}$  to  $\text{kJ}\cdot\text{min}^{-1}$ :

$$\text{Energy expenditure (kJ}\cdot\text{min}^{-1}) = (\dot{V}O_2 \times \text{kcal}\cdot\text{L}^{-1} \text{ for RQ}) \times 4.186$$

The aerobic energy expenditure ( $\text{kJ}\cdot\text{min}^{-1}$ ) during S1, S5, S6 and S10 was calculated from the above equation using expired air from the Douglas bag samples and the anaerobic energy expenditure was estimated as the total energy required minus aerobic energy expenditure. When calculating aerobic energy expenditure and total energy required, baseline  $\dot{V}O_2$  was subtracted from the exercising  $\dot{V}O_2$  during each sub-LT stage of the GXT as well as during the four sprints.

INSERT FIGURE 1 ABOUT HERE

Data are reported as mean  $\pm$  SD. The Statistical Package for the Social Sciences (SPSS) was used to carry out statistical procedures and the level of significance was set at  $p < 0.05$ . A one-way ANOVA with repeated measures was used to compare performance and physiological data between sprints. Sphericity was checked using Mauchly's test and the Greenhouse Geisser correction was used for



epsilon <0.75, while the Huynh-Feldt correction was adopted for less severe asphericity (>0.75).

Within subject differences were localised using pair-wise comparisons with a Bonferroni adjustment.

## Results

The  $\dot{V}O_{2\max}$  was  $3.06 \pm 0.43 \text{ L}\cdot\text{min}^{-1}$  and the  $t_{\text{rec}}$  was  $10.9 \pm 1.1 \text{ min}$ , with individual values ranging from 10.0 – 13.0 min. Performance,  $\dot{V}O_2$  and energy contribution data from the expired-air collection trial are displayed in Table 1. The MP decreased from the first to the last sprint during B1 and B2 by  $20 \pm 5\%$  and  $17 \pm 6\%$ , respectively, while there were no significant differences in PP or MP between the two respective sprints within each bout (i.e., S1 versus S6 and S5 versus S10) or in MP,  $PP_{\text{dec}}$  or  $W_{\text{dec}}$  between bouts ( $p>0.05$ ). The estimated anaerobic energy contribution (measured in kJ) decreased from the first to the last sprint during B1 and B2 by  $45 \pm 13\%$  and  $47 \pm 7\%$ , respectively. Neither  $\dot{V}O_2$  nor the estimated aerobic energy contribution differed significantly for respective sprints between the two bouts ( $p>0.05$ ). In addition, the  $\dot{V}O_2$  attained in S5 and S10 did not differ significantly from  $\dot{V}O_{2\max}$  ( $p=0.284$  and  $p=0.448$ , respectively). Correlations between  $\dot{V}O_{2\max}$  and the estimated aerobic energy contribution to S1, S5, S6 and S10 (measured in kJ) are displayed in Figure 2. While the  $\dot{V}O_2$  during S1 was not significantly correlated with  $\dot{V}O_{2\max}$  ( $r=0.41$ ,  $p=0.312$ ), the  $\dot{V}O_2$  was related to  $\dot{V}O_{2\max}$  during S5 ( $r=0.82$ ,  $p=0.013$ ), S6 ( $r=0.73$ ,  $p=0.039$ ) and S10 ( $r=0.89$ ,  $p=0.003$ ).

INSERT TABLE 1 ABOUT HERE

INSERT FIGURE 2 ABOUT HERE

## Discussion

The aim of the current study was to investigate the  $\dot{V}O_2$  and estimated aerobic contribution to repeated-sprint exercise during two isolated sprints (i.e., the first and the last) within two repeated-sprint bouts. Consistent with our first hypothesis, the  $\dot{V}O_2$  and estimated aerobic contribution were

greater during the final sprint versus the first sprint of both bouts. In addition,  $\dot{V}O_2$  was similar for the respective sprints within the two bouts (i.e., S1 versus S6 and S5 versus S10). In support of our second hypothesis, the estimated aerobic contribution to the final sprint of each bout was significantly related to  $\dot{V}O_{2max}$ . Moreover, the  $\dot{V}O_2$  attained in the final sprint of each bout was not significantly different from  $\dot{V}O_{2max}$ .

While previous studies have not directly measured  $\dot{V}O_2$  during short, maximal sprints, it has been suggested that 3 – 8% of the energy required during sprints lasting 10 s or less is derived from aerobic sources.<sup>11,18</sup> These values have been derived from mathematical models of metabolic energy production that rely on various assumptions, including the capacity of anaerobic metabolism and the time kinetics of aerobic and anaerobic energy delivery at the onset of exercise. The present study is the first to measure  $\dot{V}O_2$  directly and the results suggest that even 8% (i.e., the top of the previously estimated range) may under-estimate the aerobic contribution to a maximal 6-s sprint, which was calculated here as ~ 10%. The results from the present study are close to a predicted value of 9%, stated in the introduction, which was based on a linear decrease in aerobic contribution reported in earlier studies as sprint time decreases from 90 s to 30 s.<sup>9,10</sup>

Although our estimates appear consistent with this linear decrease in aerobic contribution as sprint time decreases, they must be interpreted with caution as they are based on a number of necessary assumptions. Firstly, the validity of calculating energy demands for intensities above  $\dot{V}O_{2max}$  has been criticised, with linear extrapolation beyond  $\dot{V}O_{2max}$  potentially underestimating the energy demand due to decreased efficiency at higher workloads.<sup>19</sup> In addition,  $\dot{V}O_2$  at the onset of exercise is influenced by two separate but interrelated mechanisms: a cardiodynamic phase, resulting from increased pulmonary blood flow, and a delayed increase in  $O_2$  extraction at the contracting muscles.<sup>20</sup> While it is not possible to accurately determine whether there was a cardiodynamic contribution to our  $\dot{V}O_2$  measurements, previous observations suggest that using a prior sprint during the warm-up, as was included in our experimental model, is likely to remove the cardiodynamic component from

subsequent exercise.<sup>21</sup> Furthermore, it has been reported that  $O_2$  extraction (i.e., the  $[a-v]O_2$ diff) doubles after only 6 s of intense exercise lasting 3 min.<sup>22</sup> Given that both of these studies used lower intensity exercise than the 6-s sprints used in the current study, and that the higher rates of PCr breakdown during the 6-s sprints would have greatly stimulated  $O_2$  extraction in the contracting muscles,<sup>23</sup> it is unlikely that the estimated aerobic contribution to the first sprint of each bout in the current study was affected by a cardiodynamic component.

The present study is the first to report the  $\dot{V}O_2$  and estimated aerobic contribution to the final sprint of a repeated-sprint bout. As hypothesised, the final sprint within both bouts was characterised by a higher aerobic contribution, with a 4-fold increase from the first sprint. In addition, the  $\dot{V}O_2$  during the final sprint was 2.5 – 3.0 times greater than during the first sprint of each bout. Due to the incomplete recovery between sprints, it is likely that all sprints after the first were initiated from an elevated baseline,<sup>24</sup> which would have elevated the  $\dot{V}O_2$  during subsequent sprints. In support of this, previous work has demonstrated an increase in  $\dot{V}O_2$  during the third of 10 x 6-s sprints relative to the first (albeit using breath-by-breath data analysed over complete 36-s sprint-recovery cycles), after which no further increases were reported.<sup>25</sup> In the current study, it is possible that the progressive increases in PCr breakdown and  $P_i$  accumulation over the course of the 5 x 6-s sprints would also have driven the increase in  $\dot{V}O_2$  from the first to the final sprint. Thus, the significantly greater  $\dot{V}O_2$  in the fifth sprint of each bout can probably be attributed to starting from an elevated baseline, priming as a consequence of the previous sprints, and an ADP-mediated stimulation of  $\dot{V}O_2$ .

With a progressive depletion of ATP and PCr over the course of a 5 x 6-s repeated-sprint bout, and an inability to restore these high-energy phosphates within 30 s,<sup>26</sup> our data confirm the increasing importance of aerobic energy production as more sprints are completed. Gaitanos et al.<sup>12</sup> reported that the anaerobic ATP production to 10 x 6-s sprints, separated by 30 s of recovery, was reduced by 65% from the first to the final sprint. The lower decrease in performance (27%) was hypothesised to be attributable to a supplementary increase in aerobic contribution. Data from the present study support

this theory, whereby the anaerobic contribution (measured in kJ) decreased by 45% from S1 to S5, and by 47% from S6 to S10, while MP decreased by only 20% and 17%, respectively. This mismatch between the decline in anaerobic energy contribution and performance may be attributed, at least in part, to the substantial increase in  $\dot{V}O_2$ .

A range of short-duration (i.e., 1 – 3 min), maximal exercise tests have been shown to elicit  $\dot{V}O_{2\max}$  values that do not differ from the values produced during a traditional GXT.<sup>27,28</sup> However, the current study is the first to demonstrate the attainment of  $\dot{V}O_{2\max}$  at the end of two separate 5 x 6-s repeated-sprint bouts (each lasting ~ 2 min in total). In addition, the  $\dot{V}O_2$  values attained in S5 and S10 were strongly related to  $\dot{V}O_{2\max}$ . These findings suggest that the aerobic contribution to repeated-sprint exercise may be limited by  $\dot{V}O_{2\max}$  and that by increasing this capacity a greater aerobic contribution may be achieved during latter sprints, potentially improving performance. This theory is supported by previous work showing concomitant improvements in maximal aerobic capacity and repeated-sprint performance following endurance training.<sup>29</sup>

Despite the strong correlations identified between  $\dot{V}O_{2\max}$  and both the  $\dot{V}O_2$  and aerobic energy contributions (in kJ) to both S5 and S10 in the present study, associations between  $\dot{V}O_2$  and/or  $\dot{V}O_{2\max}$  and performance are less clear. For example, no significant correlations were identified between  $\dot{V}O_{2\max}$  and MP in B1 ( $r=0.60$ ,  $p=0.116$ ) and B2 ( $r=0.60$ ,  $p=0.118$ ) or  $W_{\text{dec}}$  in B1 ( $r=0.32$ ,  $p=0.441$ ) and B2 ( $r=-0.18$ ,  $p=0.671$ ). These findings are inconsistent with previous work showing a higher  $\dot{V}O_{2\max}$  to be associated with increased MP and decreased  $W_{\text{dec}}$ .<sup>4</sup> It is possible that these differences may be explained by the smaller and more homogenous participant group used in the current study. While the specific mechanisms of improved aerobic fitness potentially enhancing RSA are still unclear, there is some evidence that muscle reoxygenation between sprints is an important factor for performance, and that this is inhibited by reduced oxygen availability.<sup>30</sup>

## Conclusion

The current study is the first to investigate the aerobic contribution to isolated sprints within a repeated-sprint bout involving 5 x 6-s sprints. The findings have shown that the aerobic contribution to the first sprint is ~ 10%, while during the fifth sprint it is ~ 40%. This significant increase in aerobic energy contribution served to offset the decline in anaerobic energy production, which was substantially greater than the reduction in work done. The aerobic contribution to the final sprint of each bout was also significantly related to  $\dot{V}O_{2\max}$ , which highlights a potential limitation to RSA. This is supported by the  $\dot{V}O_2$  attained during the final sprint of each bout, which was not different from  $\dot{V}O_{2\max}$ .

### **Practical Implications**

- !! The current findings contribute to our understanding of aerobic metabolism during repeated-sprint exercise, which is important for developing appropriate training and testing strategies for team-sport athletes;
- !! Aerobic and anaerobic energy sources are both important for repeated-sprint exercise, highlighting the need to develop both of these energy systems;
- !! Increasing  $\dot{V}O_{2\max}$  in team-sport athletes may enable increased aerobic energy delivery, and consequently work done, during the latter sprints of repeated-sprint bouts.

### Acknowledgements

The authors would like to thank the soccer players who took part in the study and the postgraduate students at the School of Sport Science, Exercise and Health at the University of Western Australia who assisted in the laboratory. No financial support was received for this study.

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372 **Tables**

373

374 Table 1: Mean  $\pm$  SD performance,  $\dot{V}O_2$  and aerobic contribution data from the expired air collection trial

	<b>S1</b>	<b>S5</b>	<b>B1</b>	<b>S6</b>	<b>S10</b>	<b>B2</b>
<b>PP (W)</b>	895 $\pm$ 88	741 $\pm$ 73 <sup>a</sup>		879 $\pm$ 66	739 $\pm$ 64 <sup>a</sup>	
<b>PP (W<math>\cdot</math>kg<sup>-1</sup>)</b>	14.6 $\pm$ 0.9	12.1 $\pm$ 1.0 <sup>a</sup>		14.4 $\pm$ 1.0	12.1 $\pm$ 1.2 <sup>a</sup>	
<b>MP (W)</b>	722 $\pm$ 86	577 $\pm$ 64 <sup>a</sup>	626 $\pm$ 63	699 $\pm$ 67	577 $\pm$ 59 <sup>a</sup>	613 $\pm$ 62
<b>MP (W<math>\cdot</math>kg<sup>-1</sup>)</b>	11.8 $\pm$ 0.9	9.4 $\pm$ 0.8 <sup>a</sup>	10.2 $\pm$ 0.7	11.4 $\pm$ 0.8	9.5 $\pm$ 0.9 <sup>a</sup>	10.0 $\pm$ 0.7
<b>PP<sub>dec</sub> (%)</b>			12 $\pm$ 4			12 $\pm$ 4
<b>W<sub>dec</sub> (%)</b>			13 $\pm$ 5			12 $\pm$ 4
<b><math>\dot{V}O_2</math> (L<math>\cdot</math>min<sup>-1</sup>)</b>	1.08 $\pm$ 0.26	2.86 $\pm$ 0.77 <sup>a,b</sup>		1.08 $\pm$ 0.46	3.14 $\pm$ 0.61 <sup>a,b</sup>	
<b><math>\dot{V}O_2</math> (% <math>\dot{V}O_{2max}</math>)</b>	35 $\pm$ 8	93 $\pm$ 17 <sup>a</sup>		35 $\pm$ 10	102 $\pm$ 10 <sup>a</sup>	
<b>Aerobic (%)</b>	9.8 $\pm$ 3.3	38.4 $\pm$ 10.3 <sup>a</sup>		9.6 $\pm$ 4.7	42.2 $\pm$ 6.4 <sup>a</sup>	

375 B: bout; MP: mean power; PP: peak power; PP<sub>dec</sub>: decrement in peak power over the sprint bout; S: sprint; W<sub>dec</sub>: decrement in work done over the 5 x 6-s  
 376 sprints

377 <sup>a</sup> significantly different from the first sprint of the respective bout (p<0.001); <sup>b</sup> not significantly different from  $\dot{V}O_{2max}$  (p>0.05)

**Figure legends**

Figure 1: An example of the relationship between power output (W) and total energy expenditure ( $\text{kJ}\cdot\text{min}^{-1}$ ) during each sub-maximal stage (filled circles) and the estimated total energy required ( $\text{kJ}\cdot\text{min}^{-1}$ ) for the first (S1) and final (S5) sprint of bout 1 (open circles)

Figure 2: Relationships between  $\dot{V}\text{O}_{2\text{max}}$  ( $\text{L}\cdot\text{min}^{-1}$ ) and the aerobic energy contribution (kJ) to each of the sprints

Figure 1

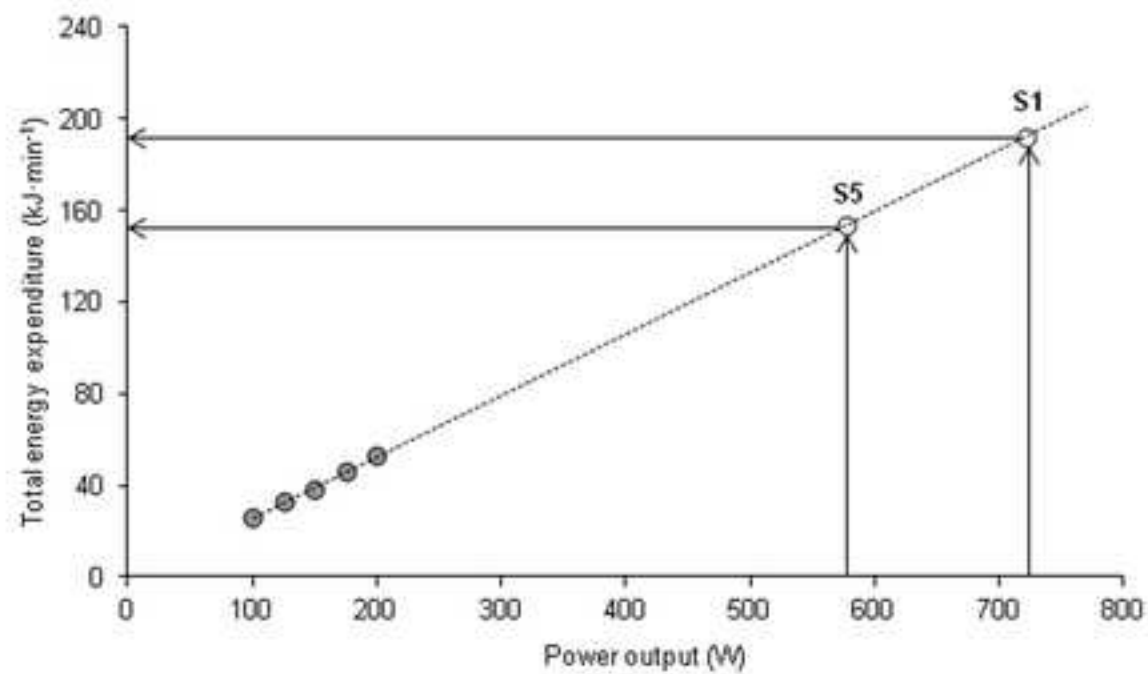


Figure 2

