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TITLE:

VO₂ attained during treadmill running: influence of specialist (400m or 800m) event

Original investigation

David V. B. James¹, Leigh E. Sandals¹, Stephen B. Draper¹, Sara Maldonado-Martín² and Dan M. Wood¹

¹Faculty of Sport, Health and Social Care. University of Gloucestershire. Oxstalls Campus. Oxstalls Lane. Gloucester, UK. ² Faculty of Physical Activity and Sport Sciences. University of the Basque Country. Vitoria-Gasteiz. Araba. Basque Country. Spain.

Tel: 00 44 (0)1242 715166

Fax: 00 44 (0)1242 715222

E-mail: djames@glos.ac.uk

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ABSTRACT

Purpose: Previously it has been observed that, in well-trained 800-m athletes, $\dot{V}O_{2\max}$ is not attained during middle-distance running events on a treadmill, even when a race type pacing strategy is adopted. Therefore, we investigated whether specialization in a particular running distance (400-m or 800-m) influences the $\dot{V}O_2$ attained during running on a treadmill. **Methods:** Six 400-m and six 800-m running specialists participated in the study. A 400-m trial, along with a progressive test to determine $\dot{V}O_{2\max}$, was completed in a counterbalanced order. Oxygen uptake attained during the 400-m trial was compared to examine the influence of specialist event. **Results:** A $\dot{V}O_2$ plateau was observed in all participants for the progressive test, demonstrating the attainment of $\dot{V}O_{2\max}$. The $\dot{V}O_{2\max}$ values were 56.2 ± 4.7 and 69.3 ± 4.5 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for the 400-m and 800-m event specialists, respectively ($p = 0.0003$). Duration for the 400-m trial was 55.1 ± 4.2 s and 55.8 ± 2.3 s for the 400-m and 800-m event specialists, respectively. The $\dot{V}O_2$ response achieved was $93.1 \pm 2.0\%$ and $85.7 \pm 3.0\%$ of $\dot{V}O_{2\max}$ for the 400-m and 800-m event specialists, respectively ($p = 0.001$). **Conclusions:** These results demonstrate that specialist running event does appear to influence the % $\dot{V}O_{2\max}$ achieved in the 400-m trial, with the 800-m specialists attaining a lower % $\dot{V}O_{2\max}$ than the 400-m specialists. The 400-m specialists appear to compensate for a lower $\dot{V}O_{2\max}$ by attaining a higher % $\dot{V}O_{2\max}$ during a 400-m trial.

KEY WORDS: VO_2 RESPONSE; ENERGETICS; AEROBIC CONTRIBUTION; TRACK ATHLETES; 400 M

INTRODUCTION

Maximal oxygen uptake ($\dot{V}O_{2\max}$) has been assumed to be of importance in determining the energetics of long sprints and middle-distance events, and as such, a useful parameter to assess performance capabilities in participants in 400-m and 800-m events.¹ However, comparatively little is known about the oxygen uptake ($\dot{V}O_2$) response to constant load exercise in the severe intensity,² which given a long enough duration can result in the attainment of $\dot{V}O_{2\max}$.³

Across all exercise intensity domains, studies have typically examined responses to cycling exercise in subjects who are not well-trained.⁴⁻¹⁰ Thus, it is rare to find a study where $\dot{V}O_{2\max}$ of subjects is in excess of 60 ml·kg⁻¹·min⁻¹. Previous studies related to middle-distance running performance in highly trained athletes, for whom $\dot{V}O_{2\max}$ would normally be in excess of 60 ml·kg⁻¹·min⁻¹,¹¹ could potentially lead to misleading interpretations regarding the energetic of middle-distance running.

The assumption that during severe intensity running $\dot{V}O_{2\max}$ will be attained, or at least that the $\dot{V}O_2$ response will tend towards $\dot{V}O_{2\max}$, has received some experimental support.^{12,13} However, the subjects in these studies were of limited aerobic fitness and such a response should not be assumed for well-trained middle-distance athletes. When well-trained subjects have performed running of a duration and intensity comparable to long sprints and middle-distance events a different response is evident. In two separate studies, Spencer and colleagues noted that $\dot{V}O_{2\max}$ is not attained.^{14,15} In one study, the $\dot{V}O_2$ attained during a range of constant speed middle-distance running events was investigated, however, the event specialists only completed a trial in their specialist event (i.e., 800-m runners only ran an 800-m trial).¹⁴ There were also some methodological concerns with the studies of Spencer and colleagues.^{14,15} Firstly, an increasing gradient protocol was used to assess $\dot{V}O_{2\max}$, which may not have been a valid index for the race pace runs that were performed. Secondly, in one of the studies, the treadmill speed was adjusted to replicate a race,¹⁵ so it is not clear whether the inability to achieve $\dot{V}O_{2\max}$ was due to decreasing exercise intensity over time. We have, however, observed a similar $\dot{V}O_2$ response even when these methodological concerns have been addressed.¹⁶⁻²⁰ During genuine square wave transitions at a speed that led to exhaustion in approximately two minutes, we have

consistently shown $\dot{V}O_2$ to plateau some way below $\dot{V}O_{2\max}$ and the plateau occurs after approximately 60 s of exercise in aerobically fit athletes.¹⁷ The data of Spencer et al¹⁴ suggest that in a 400-m run performed by shorter distance event specialists, the $\dot{V}O_2$ response may reach a submaximal plateau after only 35 s.

Svedenhag and Sjödín¹¹ have shown that $\dot{V}O_{2\max}$ differs between athletes who specialise in different events. Runners specialising in the 400-m event typically have a lower $\dot{V}O_{2\max}$ ($63.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) than those specialising in the 800-m ($68.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) or both the 800-m and 1500-m ($71.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) events. On this matter, it has also been confirmed that runners specialising in a shorter specialist event have a lower $\dot{V}O_{2\max}$.²¹ Hence, if the % $\dot{V}O_{2\max}$ attained during middle-distance running is a function of an event running specialist's $\dot{V}O_{2\max}$,¹⁹ the data of Svedenhag and Sjödín¹¹ would suggest that the potential effect of event running specialist is most likely to be apparent in the 400-m event.

The data of Spencer et al¹⁴ do not establish whether differences in % $\dot{V}O_{2\max}$ attained during treadmill middle-distance running were due to the differing specialist running event of the athletes. Therefore, the aim of the present study was to investigate the % $\dot{V}O_{2\max}$ attained during 400 m running in 400-m and 800-m event specialists. In doing this, we hoped to establish the influence of specialist event on the $\dot{V}O_2$ attained.

METHODS

Subjects

Six male runners specialising in the 800-m event (age 24.8 ± 3.2 yr; height 1.79 ± 0.1 m; mass 68.3 ± 4.9 kg) with a seasonal best time of 111.8 ± 3.7 s for the 800 m (within 11% of the 101.11 s World Record) and six male runners specialising in the 400-m event (age 21.3 ± 1.5 yr; height 1.78 ± 0.1 m; mass 74.5 ± 7.3 kg) with a seasonal best time of 50.6 ± 0.7 s for the 400 m (within 18% of the 43.2 s World Record) volunteered to participate. All were well habituated with laboratory procedures in general and with motorised treadmill running in particular. Prior to participation, all subjects completed a health screening procedure and were fully informed of the nature of the study. Subjects then provided written consent to participate. The Institutions Research Ethics Committee approved all

procedures.

Preliminary tests

On a level motorised treadmill, all subjects initially completed a progressive speed ramped test ($0.16 \text{ km}\cdot\text{h}^{-1}$ per 5 s) and a constant speed 400-m run. The progressive test allowed an appropriate starting speed to be selected for future progressive tests to ensure that exhaustion would be reached in ~ 10 min for each subject.²² The $\dot{V}\text{O}_2$ at which the gas exchange threshold occurred was determined by means of the v-slope method for each subject.²³ The corresponding speed for this $\dot{V}\text{O}_2$ was then determined from each subject's $\dot{V}\text{O}_2$ -running speed relationship, and used in the calculation of warm up speed for subsequent tests. The speed for the 400-m run was determined from each subject's seasonal best times for the event. The time to exhaustion for the 400-m constant speed run was then compared to the subjects' seasonal best times and, in cases where they differed, the speed was adjusted accordingly for future tests.

Procedures

Each subject completed a progressive test and a 400-m constant speed run. All tests were completed on a level motorised treadmill (Ergo ELG 70, Woodway, Weil and Rhein, Germany) in a counterbalanced order to control for order and carryover effects. Subjects completed their own sequence of tests at the same time of day. All tests were completed within 14 days, with at least 48 hours between each test. Each of the tests was preceded by a 5 min warm-up at 10% below the speed corresponding to each participant's gas exchange threshold to control for the effects of prior exercise on the $\dot{V}\text{O}_2$ response.⁶

The speeds for the 400-m runs were based on the findings from the preliminary tests, adjusting the velocity in order to be maximal for the test. For each run, the motorised treadmill was set at the required speed and the experimenter initiated a 10-s countdown when the subject was ready to start the test. The subject stood astride the motorised treadmill belt and at the start of the countdown used the support rails to suspend his body above the belt while he developed cadence in his legs. The test officially started, and the first collection of expiration was initiated, when the subject released the support rails and

started running on the treadmill belt. Participants were encouraged to continue running for as long as possible in all tests. On this matter, we had previously knowledge that after adjusting the speed in 400-m trial from the preliminary tests, the volitional exhaustion would complete the full 400-m distance.

Data Acquisition

Oxygen uptake was determined every ~15 s during the ramp test and throughout the entire duration of the 400-m runs using a Douglas bag technique.^{19,24} A whole number of breaths was always collected, so the actual period was never greater than 20 s or less than 10 s. Douglas bags (Cranlea and Co., Birmingham, UK) were connected to a master valve to allow continuous sampling of expiration. Each 150 L bag was fitted with a two-way bag valve (Type 343, Georg Fischer, Switzerland) so that whilst the bags were connected to the master valve the subject's expiration could be collected or the bags could be sealed and exchanged for another bag.

Data Analysis

A 30-s moving average was used to determine $\dot{V}O_{2max}$ and the highest $\dot{V}O_2$ attained (i.e., $\dot{V}O_{2peak}$) during the 400-m run.¹⁹ The averaging always started with the final 15-s sampling period and moved back towards the start of the test. All tests were analysed at an alpha level of 0.05 and all data are presented as mean \pm SD unless otherwise stated. The $\dot{V}O_{2peak}$ attained during each 400-m run was expressed as a percentage of the reference $\dot{V}O_{2max}$ value determined from the ramp test to give the % $\dot{V}O_{2max}$ attained. An independent sample t-test was used to assess if there was a difference in the % $\dot{V}O_{2max}$ attained between the 400-m and 800-m event specialists for the 400-m constant speed run.

RESULTS

During the progressive test, a $\dot{V}O_2$ -plateau was evident in all participants. For the 800-m event running specialists, the mean value for $\dot{V}O_{2max}$, derived from the 30-s moving average approach, was $69.3 \pm 4.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The peak speed attained on the ramp test was $22.3 \pm 0.8 \text{ km}\cdot\text{h}^{-1}$, compared to a speed of $25.8 \pm 1.2 \text{ km}\cdot\text{h}^{-1}$ for the 400-m run. For the

400-m event running specialists, the mean value for $\dot{V}O_{2\max}$, derived from the 30 s moving average approach, was $56.2 \pm 4.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The peak speed attained on the ramp test was $19.0 \pm 1.4 \text{ km}\cdot\text{h}^{-1}$, compared to a speed of $26.1 \pm 1.1 \text{ km}\cdot\text{h}^{-1}$ for the 400-m run. There were significant differences ($p = 0.0003$) in $\dot{V}O_{2\max}$ between the 400-m and 800-m event running specialists.

In the 400-m and 800-m event running specialists, test duration was $55.1 \pm 4.2 \text{ s}$, and $55.8 \pm 2.3 \text{ s}$ respectively for the 400-m run. The mean $\dot{V}O_{2\text{peak}}$ for the 400-m and 800-m event running specialist groups during the 400-m constant speed run was $52.8 \pm 4.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $59.4 \pm 4.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. This resulted in a mean % $\dot{V}O_{2\max}$ attained of $93.1 \pm 2.0\%$ and $85.7 \pm 3.0\%$ for the 400-m and 800-m event specialists, respectively. In Figure 1, the % $\dot{V}O_{2\max}$ attained is presented for the 400-m and 800-m event running specialist groups. There was a statistically significant difference ($p = 0.001$) in the % $\dot{V}O_{2\max}$ attained during the 400-m constant speed run between the 400-m and 800-m event running specialists.

INSERT FIGURE 1 ABOUT HERE

DISCUSSION

We investigated the influence of running specialist event (i.e., 400 m or 800 m) on the $\dot{V}O_2$ attained during treadmill running. Exercise intensity was manipulated, based on seasonal best performance times of subjects, to result in exhaustion at exactly 400-m. The 800-m event specialists ran at an average speed of $25.8 \text{ km}\cdot\text{h}^{-1}$ ($7.17 \text{ m}\cdot\text{s}^{-1}$) for 55.8 s, giving a test distance of 399.9 m. The 400-m event specialists ran at an average speed of $26.1 \text{ km}\cdot\text{h}^{-1}$ ($7.25 \text{ m}\cdot\text{s}^{-1}$) for 55.1 s, giving a test distance of 399.5 m. These results suggest that we were successful in determining the appropriate exercise intensity for treadmill 400-m running performance. The $\dot{V}O_2$ attained differed between 400-m and 800-m event specialists, where, relative to $\dot{V}O_{2\max}$, a higher $\dot{V}O_2$ was achieved by the 400 m event specialists (93% $\dot{V}O_{2\max}$) compared with the 800-m event specialists (86% $\dot{V}O_{2\max}$).

The finding in the present study that 93% $\dot{V}O_{2\max}$ can be attained during constant

speed 400 m running by 400-m event specialists with a $\dot{V}O_{2\max}$ of $56 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ is similar to findings previously reported.¹⁴ These authors showed that $\sim 98\%$ $\dot{V}O_{2\max}$ is attained during constant speed 400 m running by 400-m event specialists with a $\dot{V}O_{2\max}$ of $53 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. In contrast, it has been shown that $\sim 89\%$ $\dot{V}O_{2\max}$ is attained during constant speed 400 m running by 400-m event specialists with a higher $\dot{V}O_{2\max}$ of $59 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.¹⁵ In the present study, 800-m event specialists were also required to complete a 400-m test, which showed that 800-m event specialists only attained 86% $\dot{V}O_{2\max}$.

The influence of event specialist was not addressed by Spencer et al¹⁴ or Spencer and Gastin¹⁵ since the event specialists completed only their preferred event. Whether the difference in the % $\dot{V}O_{2\max}$ attained during 400 m running between 400-m and 800-m event running specialists in the present study is due to the difference in $\dot{V}O_{2\max}$ rather than some other difference in the characteristics of the 400-m and 800-m event specialist groups requires further investigation. Although we attempted to match the groups as closely as possible in relation to World record times in their respective events, it should be acknowledged that the 400-m group had relatively slower seasonal best times. Such a discrepancy between the group characteristics should be acknowledged as a further potential confounding influence on the findings, although the physiological characteristics of the athletes in each group were completely in accordance with the findings of Svedenhag and Sjödin¹¹. Models of middle-distance running performance may need revision to accommodate this relationship between specialist event and the % $\dot{V}O_{2\max}$ attained.

It appears that over the closing stages of an exhaustive run at 400-m pace $\dot{V}O_2$ plateaus in 800-m specialists but continues to rise in 400-m specialists (Figure 1), suggesting that the overall kinetics of the $\dot{V}O_2$ response may depend on the specialist event of the subject. It is unlikely that the $\dot{V}O_2$ response to an exhaustive run at 400-m pace includes a slow component in subjects whose aerobic fitness is high. The $\dot{V}O_2$ slow component has typically been reported to emerge after 80 to 110 s,³ although the studies on which this statement was based all involved exercise lasting at least 360 s. There are very few studies in which the $\dot{V}O_2$ response has been modelled for exhaustive exercise lasting

120 s or less.^{2,9,10,17,25} The study by Hughson et al,² examining untrained subjects cycling at $\sim 125\% \dot{V}O_{2\max}$, used a two-component model that included an additional, slower component. The justification for this approach was based on smaller residuals of the model fit. The mean delay for the second (slow) component was 40.5 ± 17.5 s, suggesting that the slow component emerged somewhat earlier than has previously been reported for lower intensities. For cycling exercise at $105\% \dot{V}O_{2\max}$, terminating after ~ 165 s, it was found that four of the seven subjects presented data that were better fit with a two component-model.⁹ However, when cycling exercise at $105\% \dot{V}O_{2\max}$ was examined in a different group of subjects (terminating after ~ 130 s), a mono-exponential model was found to better fit the data.¹⁰ However, it should also be noted that these studies have been conducted on cycle ergometer in relatively untrained subjects ($\dot{V}O_{2\max} < 52 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). In running exercise, both Draper and Wood¹⁷ and Carter et al²⁵ used a mono-exponential model to describe the $\dot{V}O_2$ response in aerobically fit runners (69 and 59 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively). Again, the justification for this approach was based on examination of the residuals of the model fit with Carter et al²⁵ reporting that fitting the data with a more complex three-component exponential model did not lead to a significantly better fit. Further research is required to definitively establish the influence of both exercise duration/intensity and aerobic fitness on when (if at all) the $\dot{V}O_2$ -slow component emerges, but available evidence suggests that a slow component is not evident in exercise leading to exhaustion in less than 120 s.

For heavy intensity cycling, high aerobic fitness has been shown to be associated with a relatively high gain for the primary component and a relatively low gain for the slow component.²⁶ Interestingly, Scheuermann and Barstow²⁷ report that the difference between the predicted $\dot{V}O_2$ (based on the below gas exchange threshold $\dot{V}O_2$ -work rate relationship) and the attained $\dot{V}O_2$ (at the end of the primary phase of the $\dot{V}O_2$ response) for exhaustive cycling lasting between 180 and 300 s is positively correlated with aerobic fitness. If it is accepted that the $\dot{V}O_2$ response of aerobically fit subjects to exhaustive running lasting ~ 120 s or less is dominated by the primary component, the lower $\% \dot{V}O_{2\max}$ attained in the present study in the more aerobically fit 800-m event specialists (compared with the 400-m event specialists) is clearly consistent with these previous

findings.²⁷ It therefore seems plausible that the $\dot{V}O_2$ response to exhaustive 400 m running is dominated by the primary component in 800-m specialists (whose aerobic fitness is high) but may include a discernable slow component in 400-m specialists (whose aerobic fitness is lower).

Draper and Wood¹⁷ reported that in aerobically trained runners (mean $\dot{V}O_{2max}$ of $69 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) the $\dot{V}O_2$ response may be considerably quicker than that which has been reported in previous studies of treadmill running.^{7,28,29} For the mono-exponential response described, the time constant averaged 10.7 s, emerging after an average delay of 11.2 s, suggesting a complete response in ~54 s (i.e., delay + [4 x time constant]). More recently, Carter et al²⁵ has also found that in reasonably aerobically fit subjects (mean $\dot{V}O_{2max}$ of $59 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) exercising at 120% $\dot{V}O_{2max}$, the time constant averaged 12.5 s, emerging after no delay, suggesting a complete response in ~50 s. These findings are consistent with the observation of Scheuermann and Barstow²⁷ that the time constant for the primary component of the $\dot{V}O_2$ response is negatively correlated with $\dot{V}O_{2max}$, and explains why the $\dot{V}O_2$ response of the 800-m specialists in the present study appeared to level off over the final seconds of the 400-m run (Figure 1).

We chose to focus exclusively on the aerobic contribution to energy production during the 400-m trials. Other authors have attempted to estimate the contribution of aerobic and anaerobic sources of energy. For example, Newsholme et al (1994) suggested that in 400-m and 800-m events the mean aerobic contribution was 25% and 50%, respectively, and 75% and 50% from anaerobic sources (creatine phosphate and glycolysis) respectively. Spencer and Gastin (2001) estimated a larger proportional aerobic contribution to the energy supply in the 400-m and 800-m events (43% and 66% respectively). Our findings suggest that any estimates of aerobic energy contribution that assume that $\dot{V}O_{2max}$ is attained in the 400-m event might require reconsideration. Furthermore, 800-m event specialists might realise less of their maximal aerobic power than 400-m event specialists.

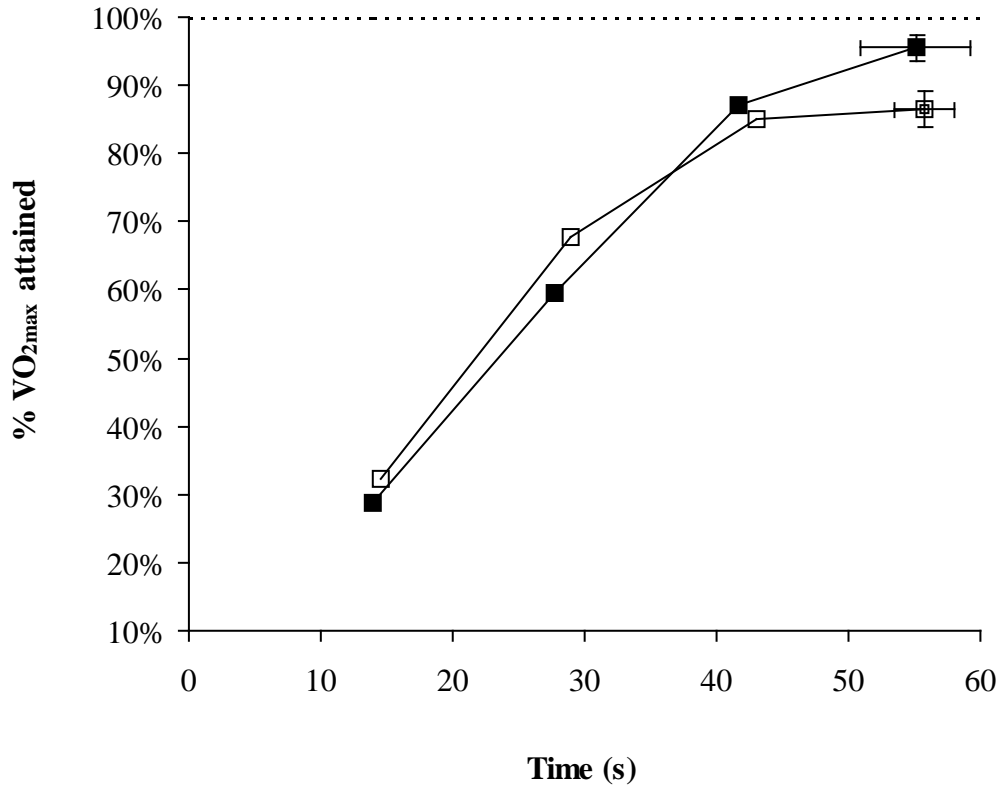
Conclusion

In conclusion, specialist running event influences the lack of attainment of $\dot{V}O_{2max}$ in well

trained aerobically fit runners. Specifically, specialist running event appears to influence the % $\dot{V}O_{2\max}$ attained, such that 400-m event specialists attain a higher % $\dot{V}O_{2\max}$ compared with 800-m event specialists, which appears to compensate for their lower $\dot{V}O_{2\max}$. These findings have implications for the energetic of middle-distance running, and models that attempt to predict performance in middle-distance running events.

Figure 1: % $\dot{V}O_{2\max}$ attained during the constant speed 400 m run in 400 m (■)
and 800 m (□) event specialists

Figure 1. David V. B. James et al



References

1. Wood DM. Physiological demands of middle-distance running. In: Fallowfield JL, Wilkinson DM, editors. *Improving Sports Performance in Middle and Long-Distance Running*. Chichester, UK: Wiley: 1999.
2. Hughson RL, O'Leary DD, Betik AC, Hebestreit H. Kinetics of oxygen uptake at the onset of exercise near or above peak oxygen uptake. *J Appl Physiol* 2000; **88**(5):1812-1819.
3. Gaesser GA, Poole DC. The slow component of oxygen uptake kinetics in humans. *Exerc Sport Sci Rev* 1996; **24**:35-71.
4. Bearden SE, Henning PC, Bearden TA, Moffatt RJ. The slow component of VO(2) kinetics in very heavy and fatiguing square-wave exercise. *Eur J Appl Physiol* 2004; **91**(5-6):586-594.

5. Endo M, Usui S, Fukuoka Y, Miura A, Rossiter HB, Fukuba Y. Effects of priming exercise intensity on the dynamic linearity of the pulmonary VO₂ response during heavy exercise. *Eur J Appl Physiol* 2004; **91**(5-6):545-554.
6. Gerbino A, Ward SA, Whipp BJ. Effects of prior exercise on pulmonary gas-exchange kinetics during high-intensity exercise in humans. *J Appl Physiol* 1996; **80**(1):99-107.
7. Hill DW, Halcomb JN, Stevens EC. Oxygen uptake kinetics during severe intensity running and cycling. *Eur J Appl Physiol* 2003; **89**(6):612-618.
8. Whipp BJ, Ward SA, Lamarra N, Davis JA, Wasserman K. Parameters of ventilatory and gas exchange dynamics during exercise. *J Appl Physiol* 1982; **52**(6):1506-1513.
9. Wilkerson DP, Campbell IT, Jones AM. Influence of nitric oxide synthase inhibition on pulmonary O₂ uptake kinetics during supra-maximal exercise in humans. *J Physiol* 2004; **561**(Pt 2):623-635.
10. Wilkerson DP, Koppo K, Barstow TJ, Jones AM. Effect of prior multiple-sprint exercise on pulmonary O₂ uptake kinetics following the onset of perimaximal exercise. *J Appl Physiol* 2004; **97**(4):1227-1236.
11. Svedenhag J, Sjodin B. Maximal and submaximal oxygen uptakes and blood lactate levels in elite male middle- and long-distance runners. *Int J Sports Med* 1984; **5**(5):255-261.
12. Hill DW, Ferguson CS. A physiological description of critical velocity. *Eur J Appl Physiol Occup Physiol* 1999; **79**(3):290-293.
13. Hill DW, Stevens EC. The VO₂ response at the onset of severe intensity exercise. *Can J Appl Physiol* 2001; **26**(4):350-355.
14. Spencer MR, Gastin PB. Energy system contribution during 400 to 1500 metres running. *New Studies Athletics* 1996; **11**:59-65.
15. Spencer MR, Gastin PB. Energy system contribution during 200- to 1500-m running in highly trained athletes. *Med Sci Sports Exerc* 2001; **33**(1):157-162.
16. Draper SB, Wood DM, Fallowfield JL. The VO₂ response to exhaustive square wave exercise: influence of exercise intensity and mode. *Eur J Appl Physiol* 2003; **90**(1-2):92-99.
17. Draper SB, Wood DM. The VO₂ response for an exhaustive treadmill run at 800-m pace: a breath-by-breath analysis. *Eur J Appl Physiol* 2005; **93**(4):381-389.
18. Draper SB, Wood DM. The oxygen uptake response of sprint- vs. endurance-trained runners to severe intensity running. *J Sci Med Sport* 2005; **8**(2):233-243.

19. James DV, Sandals LE, Wood DM. Influence of maximal oxygen uptake on oxygen uptake attained during treadmill middle distance running. *J Sports Science* . 2006.

Ref Type: In Press

20. Sandals LE, Wood DM, Draper SB, James DV. Influence of pacing strategy on oxygen uptake during treadmill middle-distance running. *Int J Sports Med* 2006; **27**(1):37-42.
21. Maldonado S, Mujika I, Padilla S. Influence of body mass and height on the energy cost of running in highly trained middle- and long-distance runners. *Int J Sports Med* 2002; **23**(4):268-272.
22. Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K, Whipp BJ. Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol* 1983; **55**(5):1558-1564.
23. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. *J Appl Physiol* 1986; **60**(6):2020-2027.
24. James DV, Barnes AJ, Lopes P, Wood DM. Heart rate variability: response following a single bout of interval training. *Int J Sports Med* 2002; **23**(4):247-251.
25. Carter H, Pringle JS, Barstow TJ, Doust JH. Oxygen uptake kinetics during supra VO₂max treadmill running in humans. *Int J Sports Med* 2006; **27**(2):149-157.
26. Barstow TJ, Jones AM, Nguyen PH, Casaburi R. Influence of muscle fiber type and pedal frequency on oxygen uptake kinetics of heavy exercise. *J Appl Physiol* 1996; **81**(4):1642-1650.
27. Scheuermann BW, Barstow TJ. O₂ uptake kinetics during exercise at peak O₂ uptake. *J Appl Physiol* 2003; **95**(5):2014-2022.
28. Carter H, Jones AM, Barstow TJ, Burnley M, Williams C, Doust JH. Effect of endurance training on oxygen uptake kinetics during treadmill running. *J Appl Physiol* 2000; **89**(5):1744-1752.
29. Carter H, Pringle JS, Jones AM, Doust JH. Oxygen uptake kinetics during treadmill running across exercise intensity domains. *Eur J Appl Physiol* 2002; **86**(4):347-354.