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Original Paper: Training and Testing

Title

Influence of pacing strategy on oxygen uptake during treadmill middle-distance running

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Running title: Pacing and oxygen uptake during treadmill running

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Abstract

The oxygen uptake ($\dot{V}O_2$) attained during a constant speed 800 m pace trial on a treadmill is less than the maximal $\dot{V}O_2$ ($\dot{V}O_{2\,max}$) in male middle-distance runners with a high $\dot{V}O_{2\,max}$ (i.e., >65 ml.kg^{-1}.min^{-1}. We therefore investigated whether the $\dot{V}O_2$ attained was influenced by the pacing strategy adopted. Eight male middle-distance runners (age 25.8 ± 3.3 years; height 1.78 ± 0.10 m; mass 67.8 ± 4.7 kg) with a personal best 800 m time of 112.0 ± 3.3 s volunteered to participate. Subjects undertook a speed ramped progressive test to determine $\dot{V}O_{2\,max}$ and three 800 m pace runs to exhaustion all in a randomised order. The three 800 m pace runs included constant speed, acceleration, and race simulation runs. Oxygen uptake was determined throughout each test using 15 s Douglas bag collections. Following the application of a 30 s rolling average, the highest $\dot{V}O_2$ during the progressive test (i.e., $\dot{V}O_{2\,max}$) and the highest $\dot{V}O_2$ during the 800 m pace runs (i.e., $\dot{V}O_{2peak}$) were compared.

For the eight runners, $\dot{V}O_{2\,max}$ was 67.2 ± 4.3 ml.kg^{-1}.min^{-1}. $\dot{V}O_{2peak}$ was 60.1 ± 5.1 ml.kg^{-1}.min^{-1}, 61.1 ± 5.2 ml.kg^{-1}.min^{-1}, and 62.2 ± 4.9 ml.kg^{-1}.min^{-1}, yielding values of $89.3 \pm 2.4\%$, $90.8 \pm 2.8\%$, and $92.5 \pm 3.1\%$ $\dot{V}O_{2\,max}$ for the constant speed, acceleration and race simulation runs, respectively. Across runs, repeated measures ANOVA revealed a significant effect ($p = 0.048$). Trend analysis identified a significant linear trend ($p = 0.025$) with the % $\dot{V}O_{2max}$ attained being higher for the acceleration run than the constant speed run, and higher still for the race simulation run. These results demonstrate that in middle-distance runners a) pacing strategy influences the $\dot{V}O_2$ attained, with a race simulation run elevating the $\dot{V}O_2$ attained compared with other pacing strategies, and b) regardless of pacing strategy the $\dot{V}O_2$ attained in an 800 m pace run on a treadmill is less than $\dot{V}O_{2\,max}$.

Key words

Pacing, maximal oxygen uptake, middle-distance running

Introduction

The pacing strategies employed in the 800 m track event in international competitions demonstrate that a relatively fast start over the initial 200 m is the preferred strategy. Performances within two percent of the world record time are run with a first 200 m at 107.4%, the middle 400 m at 98.3%, and the last 200 m at 97.5% of the average speed sustained over the entire 800 m (IAAF personal communication). However, due to the limited data available on the pacing strategies used in middle-distance running, and the physiological responses to such strategies, the values ascribed to the parameters in the models of middle-distance running performance (e.g., 3) are typically based on data determined from constant speed running on a treadmill. Such constant speed running protocols are normally administered as a 'square wave', where the subject is lowered onto a treadmill belt that is moving at the desired speed. As well as not reflecting competitive race strategies, a square wave type protocol also fails to account for the initial acceleration phase at the start of an 800 m run, and its potential impact on physiological responses.

Whilst not specifically concerned with 800 m running, two previous studies have examined the influence of differing pacing strategies in middle-distance running (1; 11). During a ~200 s run, Léger and Ferguson (11) found the % $\dot{V}O_{2max}$ attained for the slow start strategy (90%) was slightly higher than that attained using the fast start strategy (88%). During a 240 s run, Ariyoshi et al. (1) found no difference in the final $\dot{V}O_2$ attained between any of the employed pacing strategies.

It is interesting to note, however, that in the studies of Léger and Ferguson (11) and Ariyoshi et al (1), even though the duration of the runs was in excess of 200 s, the $\dot{V}O_2$ attained plateaued at ~ 90% of $\dot{V}O_{2max}$. The inability to attain $\dot{V}O_{2\,max}$ has been more recently demonstrated during constant speed (800 m pace) treadmill running of a duration similar to the 800 m event (~120 s) (4). It appears, however, that the inability to attain $\dot{V}O_{2\,max}$ is only a feature of those with a high $\dot{V}O_{2\,max}$, since Hill & Ferguson (7) studied the $\dot{V}O_2$ response to exhaustive running lasting ~130 s in subjects with a $\dot{V}O_{2\,max}$ of 52.7 ml.kg^{-1}.min^{-1}, and found the highest $\dot{V}O_2$ attained was 98% $\dot{V}O_{2\,max}$. In the studies by Ariyoshi et al (1), Leger & Feguson (11) and Draper & Wood (4), the $\dot{V}O_{2\,max}$ of the participants was 66, 73 and 69

ml.kg^{-1}.min^{-1} respectively. This is an important distinction, since the $\dot{V}O_{2\,max}$ of 800 m runners would normally be well in excess of 60 ml.kg^{-1}.min^{-1} (17). To date, Draper & Wood (4) is the only study to model the $\dot{V}O_2$ response to constant speed running exercise, where the $\dot{V}O_2$ demand is in excess of $\dot{V}O_{2\,max}$ in highly trained runners ($\dot{V}O_{2\,max}$ 68.9 ml.kg^{-1}.min^{-1}). A single exponential model was fit to breath-by-breath data, and showed that $\dot{V}O_2$ increased, after a delay of 11.2 s, with a time constant of 10.7 s. Only 85% $\dot{V}O_{2\,max}$ was attained during the exhaustive run, despite the fact that $\dot{V}O_2$ had reached an asymptote after approximately 60 s. These data demonstrate that, in the aerobically fit, an 800 m pace run provides adequate time to see a complete, but limited, $\dot{V}O_2$ response. It is therefore of interest to investigate whether the attained $\dot{V}O_2$ is an artefact of the constant speed treadmill protocol.

In the studies that have investigated pacing strategies (1; 11) during short duration (i.e., < 240 s) running, there has been no clear rationale for the strategies adopted, since they did not reflect those used in competitive events. To date, no study has investigated the $\dot{V}O_2$ attained during 800 m treadmill running, taking into consideration the acceleration phase and the pacing strategies used in competition. We therefore investigated the influence of an acceleration phase with and without a pacing strategy on the $\dot{V}O_2$ attained during 800 m pace treadmill running.

Methods

Subjects

Eight male middle-distance runners (age 25.8 ± 3.3 yr; height 1.78 ± 0.10 m; mass 67.8 ± 4.7 kg) volunteered to participate. These runners had a personal best time of 112.0 ± 3.3 s for the 800 m, which is within 11% of the World Record (101.11 s). 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. All procedures were approved by the University of Gloucestershire Research Ethics Committee.

Preliminary tests

All subjects initially completed two familiarisation runs; a speed ramped progressive test (0.16 km.h^{-1} per 8 s) and an 800 m pace run with an acceleration phase on a level treadmill (Ergo ELG 70, Woodway, Weil and Rhein, Germany). The ramp test allowed an appropriate starting speed to be selected for future ramp tests to ensure that exhaustion would be reached in ~ 10 min for each subject. The criterion for determination of $\dot{V}O_{2\,max}$ was a plateau in $\dot{V}O_2$ with an increase in speed. The $\dot{V}O_2$ at which the gas exchange threshold occurred was determined by means of the v-slope method (2) for each subject, and used to determine a warm up intensity 10% below the gas exchange threshold. The 800 m pace run allowed the subjects to become familiar with the acceleration phase and the starting procedure for this run. The speed for the 800 m pace run was determined from each subject's seasonal best time for the 800 m event. The time to exhaustion for this run was then compared to the subject's seasonal best time. If the two times differed markedly, the speed was adjusted accordingly for all future tests.

To determine the acceleration at the start of an 800 m pace run, six of the subjects individually performed the first 200 m of an 800 m outdoor track run as they would at the start of a competitive event. Electronic timing lights were placed at 5, 10, 15, 20, 25, 50, 100, and 150 m from the start. A mean group speed for each section was then derived from repeat runs (Figure 1).

INSERT FIGURE 1 ABOUT HERE

Figure 1 shows that speed had peaked by 25 m but declined relatively little thereafter. The relationship between speed and distance during the starting acceleration phase appears to be approximately exponential and so was modelled as an exponential function, given by:

$$V(s) = A\,(1 - e^{-s/\tau}) \qquad\qquad (1)$$

where V is speed in m.s^{-1}, s is the distance in m, A is the asymptote value, and τ is a rate constant. A group value (5.3 m) for τ was derived and applied to all subjects. The acceleration runs, therefore, consisted of an exponential acceleration phase over the first 25 m projecting to the constant speed, which was then sustained for the remainder of the run.

General procedures

Each subject completed one speed ramped progressive test (0.16 km.h^{-1} per 8 s) and three 800 m pace runs all on a level motorised treadmill. The preliminary tests described above were always completed first, but thereafter the eight subjects completed the four tests in a random order. 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 successive test sessions.

The three 800 m pace runs included a constant speed (C_{run}) (100% throughout), acceleration (A_{run}) (acceleration to 100%), and race simulation (R_{run}) (acceleration to 107.5% followed by speed decline) run. With the exception of the acceleration phase, all runs were designed to elicit the same average speed based on the subjects' most recent best performance and adjusted following the preliminary test if necessary. Each of the tests (excluding the preliminary test) was preceded by a 5 min warm-up at 10% below the speed corresponding to the participant's gas exchange threshold to control for the effects of prior exercise on the determination of $\dot{V}O_2$ (6). Subjects were encouraged to continue running for as long as possible in all tests.

Protocols

For the constant speed 800 m pace run (C_{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. Measurements were initiated, when the subject released the support rails and started running on the treadmill belt.

The acceleration start 800 m pace run (A_{run}) consisted of an acceleration phase over the first 25 m projecting to the constant speed, which was then sustained for the remaining duration of the test. The nature of the acceleration phase was determined from preliminary testing (see Preliminary tests section). The acceleration profile was programmed for each subject via the computer interface to the motorised treadmill. The A_{run} was conducted in a similar manner to to the C_{run} except the subject started from walking. A walking start, as opposed to a standing one, was necessary for safety reasons.

For the first 200 m of the race simulation run (R_{run}) equation (1) was used with an asymptote of 107.4% of the speed of the constant speed run. After 200 m, the speed was gradually decreased to 98.3% for the following 400 m. The final 200 m was run at 97.5% of the speed of the constant speed run.

Data Acquisition

Oxygen uptake was determined every ~15 s during the ramp test and throughout the entire duration of the 800 m pace runs using a Douglas bag technique. A whole number of breaths was always collected, so the actual period was never greater than 20 or less than 10 s. 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 each 800 m pace run. Procedures for determining $\dot{V}O_2$ are described by James et al (10), with the exception of the means of collecting expired gas continuously. Douglas bag valves were connected to a two-way master valve (Hans Rudolph Inc., Kansas, USA) to allow continuous sampling of expirate. Test–retest reliability for the $\dot{V}O_2$ attained in an 800 m pace run has been determined in our laboratory as $\pm$ 2.3 ml.kg^{-1}.min^{-1} using a limits of agreement (95%) approach.

Data Analysis

All data are presented as mean $\pm$ SD unless otherwise stated. Differences among the % $\dot{V}O_{2max}$ attained in the three 800 m pace runs were evaluated using repeated measures ANOVA. The degrees of freedom were corrected for any violation of the sphericity assumption in line with the recommendations of Huynh and Feldt (9). That is, the Huynh-Feldt correction was used when an estimate of the true value for ε [the average of the Huynh-Feldt and the Greenhouse-Geisser ε] was > 0.75 and the Greenhouse-Geisser correction was used when this estimate was < 0.75. For our analysis the estimate of the true value for ε was 0.677, so we used the Greenhouse-Geisser correction. Trends were evaluated through analysis of orthogonal contrasts which were used to describe the influence of pacing on the % $\dot{V}O_{2max}$ attained. All tests were analysed at an alpha level of 0.05.

Results

A plateau in $\dot{V}O_2$ with increasing speed for the progressive test demonstrates that the criterion for $\dot{V}O_{2\,max}$ was met for all subjects. The value for $\dot{V}O_{2max}$ was 67.2 ± 4.3 ml.kg^{-1}.min^{-1}.

Figure 2 shows data from a representative subject with a $\dot{V}O_{2max}$ determined from the ramp test of 65.0 ml.kg^{-1}.min^{-1}. $\dot{V}O_{2peak}$ is 56.2 ml.kg^{-1}.min^{-1}, 58.1 ml.kg^{-1}.min^{-1}, and 61.6 ml.kg^{-1}.min^{-1}, yielding 86.4, 89.4, and 94.7% $\dot{V}O_{2max}$ attained during the C$_{run}$, A$_{run}$ and R$_{run}$, respectively.

INSERT FIGURE 2 ABOUT HERE

The time to exhaustion was similar for the C$_{run}$ (107.9 ± 20.7 s), A$_{run}$ (110.7 ± 15.3 s) and the R$_{run}$ (111.2 ± 20.0 s) ($p = 0.612$). The mean $\dot{V}O_{2peak}$ was 60.1 ± 5.1 ml.kg^{-1}.min^{-1}, 61.1 ± 5.2 ml.kg^{-1}.min^{-1}, and 62.2 ± 4.9 ml.kg^{-1}.min^{-1}, yielding 89.3 ± 2.4, 90.8 ± 2.8, and $92.5 \pm 3.1\%$ $\dot{V}O_{2\,max}$ for the C$_{run}$, A$_{run}$ and R$_{run}$, respectively. These mean group data are shown in Figure 3. The repeated measures ANOVA revealed a significant difference ($p = 0.048$), with analysis of orthogonal contrasts revealing a significant linear trend ($p = 0.025$) (the quadratic trend was not significant, $p = 0.075$), exposing that the % $\dot{V}O_{2max}$ attained was highest for the R$_{run}$, followed by the A$_{run}$, followed by the C$_{run}$.

INSERT FIGURE 3 ABOUT HERE

Discussion

The aim of the present study was to examine the influence of pacing strategy on the $\dot{V}O_2$ attained during 800 m pace running on a treadmill. The findings demonstrate that, in comparison to a constant speed run (60.1 ml.kg^{-1}.min^{-1}, 89.3 % $\dot{V}O_{2\,max}$), the $\dot{V}O_2$ attained increases for an acceleration start run (61.1 ml.kg^{-1}.min^{-1}, 90.8 % $\dot{V}O_{2\,max}$) and increases further for a race simulation run (62.2 ml.kg^{-1}.min^{-1}, 92.5 % $\dot{V}O_{2\,max}$). These findings suggest that the $\dot{V}O_2$ attained during a 'square wave' type constant speed 800 m pace run is slightly, but significantly, lower than the that attained during either a constant speed run with an

acceleration start, or a race simulation run with acceleration to a fast start.

In order to provide an objective sense of how meaningful our findings are we examined the effect size for the difference between the $\dot{V}O_2$ attained in the C_{run} and R_{run} (i.e., 3.2%). By following the approach of Lipsey (12), we revealed an effect size of 1.25, which is considered to be a large effect (i.e., >0.8). But, despite R_{run} driving the $\dot{V}O_2$ attained to a meaningfully higher value compared with C_{run}, the $\dot{V}O_2$ attained still failed to reach $\dot{V}O_{2\,max}$.

The findings for the constant speed 'square wave' run in the present study are in agreement with the studies of Draper et al (5) and Draper & Wood (4) who showed that ~ 90% $\dot{V}O_{2max}$ is attained in middle-distance runners with a similarly high $\dot{V}O_{2max}$ (~ 65 ml.kg^{-1}.min^{-1}). However, to date, only two studies have examined the influence of pacing, and no studies have examined the influence of the initial acceleration, on the $\dot{V}O_2$ attained during middle-distance running.

Even though the studies by Leger & Feguson (11) and Ariyoshi et al (1) examined the $\dot{V}O_2$ attained during longer duration (>200 s) middle-distance events, they showed that regardless of pacing strategy, 90% $\dot{V}O_{2\,max}$ was never exceeded. The highest % $\dot{V}O_{2max}$ attained in the present study was 92.5% for the race simulation run. The ability of the race simulation run to elevate the $\dot{V}O_2$ attained in the present study was not demonstrated in the study by Léger & Ferguson (11) who found the fast start to elicit only 88% $\dot{V}O_{2\,max}$ in contrast to 90% for the slow start during an exhaustive ~ 200 s run. Ariyoshi et al. (1) found no difference in the final $\dot{V}O_2$ attained between any of the pacing strategies during 240 s of exhaustive running. A possible explanation for the lower attained $\dot{V}O_2$ following the fast start in the Leger & Ferguson study is the 'very slow' finish pace (98.4%), however, this is an unlikely explanation, since the finish pace in the present study was relatively slower (97.5%).

The only other difference between the studies was the fact that we studied 800 m running (~110 s) whereas Leger & Ferguson and Ariyoshi & colleagues studied durations in excess of 200 s. However, the shorter duration (~110 s), and therefore higher intensity, in the present study is unlikely to explain the contrast with previous findings, since Draper & Wood (4)

have shown that 120 s of constant speed exhaustive running at 800 m pace provides time for the attainment of a complete $\dot{V}O_2$ response in 800 m runners with a high $\dot{V}O_{2max}$ (69 ml.kg^{-1}.min^{-1}). For the mono-exponential response described by Draper & Wood (4), the time constant averaged 10.7 seconds. This is considerably faster than has been reported in previous studies of treadmill running (e.g., 8) but consistent with the observation of Scheuermann & Barstow (15) that the time constant for the primary component of the $\dot{V}O_2$ response is shorter in the aerobically fit. This short time constant, when coupled with the average delay of 11.2 seconds, explains why the $\dot{V}O_2$ response of these runners appeared to plateau over the final minute of the run: the mean values indicate that, on average, 99% of the asymptotic amplitude would have been attained after 60.4 seconds. Evidence therefore exists that the $\dot{V}O_2$ response to constant speed 'square wave' 800 m pace running is complete.

The acceleration phase alone, or in combination with a fast start race simulation pacing strategy, significantly (and meaningfully) increased the $\dot{V}O_2$ attained by 1.5 and 3.2% respectively for the 800 m pace runs. If it is accepted that the constant speed 800 m pace run provides adequate time for a complete $\dot{V}O_2$ response (see 4), it is interesting to explore why an acceleration start and fast start increase the asymptote of this $\dot{V}O_2$ response.

The majority of the $\dot{V}O_2$ response reflects oxygen consumption of the exercising muscle (13). It is therefore not surprising that considerable attention has been focused on muscle fibre recruitment in connection with the $\dot{V}O_2$ response to supra-lactate threshold exercise (e.g., 14). It is possible that the acceleration run and the race simulation run demanded more of certain fibres in the early stages, resulting in fatigue of those fibres. The result may have been a greater recruitment of fibres, some of which may have been less efficient (e.g., 16; 18). The recruitment of a greater number of fibres in total, or a greater proportion of type II fibres, in the acceleration and race simulation runs could influence the $\dot{V}O_2$ attained. In comparison with type I fibres, type II fibres are known to rely to a greater extent on the less efficient α–glycerophosphate shuttle, perhaps due to a saturation of the malate-aspartate shuttle (20), resulting in a lower P:O ratio. This lower P:O ratio would in turn result in an increased oxygen O_2 demand (for a given rate of ATP turnover).

The duration for which a given type of fibres are recruited might also influence the extent to

which perfusion (and thus presumably O_2 supply) matches the metabolic demand. Both the percentage of type I muscle fibres and the capillary:fibre ratio have been shown to be positively correlated with the gain of the primary component of the $\dot{V}O_2$ response for severe intensity cycling (14). It is conceivable that metabolism-perfusion matching is better after an acceleration start or a relatively fast start compared with a constant speed 'square wave' start.

Wasserman et al (19) propose a potential mechanism whereby increased O_2 supply occurs in concert with an increased O_2 demand. In fact, Wassermann and colleagues argue that time-dependent changes in pH (be it of the blood or the muscle) may be responsible both for creating an elevated O_2 demand and for providing the means of meeting this elevated demand (via the Bohr effect). In relation to the O_2 demand, Wassermann and colleagues hypothesise that a decrease in muscle pH invokes a shift from the malate-aspartate shuttle to the less efficient α–glycerophosphate shuttle, thus increasing the O_2 demand. It is possible that the acceleration and race simulation 'fast start' runs resulted in conditions necessary to concurrently enhance O_2 demand and supply, resulting in the attainment of a higher $\dot{V}O_2$.

In contrast to studies examining constant speed (i.e., square wave) treadmill running (e.g., 4), the present study attempted to examine the influence of factors involved in actual race performance on the $\dot{V}O_2$ attained. However one such factors, namely warm-up intensity, has been controlled at a moderate intensity, whereas in practice part of the warm-up is likely to be of a higher intensity. The rationale for retaining a moderate intensity warm-up was to enable valid comparisons with previous studies that have almost exclusively conducted a moderate intensity warm-up (e.g., 4). The influence of a heavy intensity warm-up on the $\dot{V}O_2$ response to subsequent heavy intensity cycling has been shown to appreciably speed the primary response, but have no effect on the highest $\dot{V}O_2$ achieved (6). However, since no studies have considered the effect of warm-up intensity on the $\dot{V}O_2$ response to severe intensity running, for which the estimated $\dot{V}O_2$ demand is in excess of $\dot{V}O_{2\,max}$, it is difficult to say what effect a higher intensity warm-up might have had on our findings.

Models of middle-distance running make the assumption that the parameter representing the highest $\dot{V}O_2$ attained is $\dot{V}O_{2\,max}$ (e.g., 3). For 800 m pace treadmill running, the findings of the present study suggest that constant speed (i.e., square wave) treadmill running elicits a

lower attained $\dot{V}O_2$ compared with race simulation 800 m pace running or constant speed running following an acceleration start. Additionally, even though the attained $\dot{V}O_2$ is greater in race simulation 800 m pace treadmill running, the $\dot{V}O_2$ attained is less than $\dot{V}O_{2\,max}$. These findings also have implications for exercise testing protocols. Clearly if the aim is to describe the $\dot{V}O_2$ kinetic response to middle-distance running, a constant speed (i.e., square wave) protocol is required. However, if the attainable $\dot{V}O_2$ is of interest, a failure to attempt to simulate track running will provide an artificially reduced value. The reasons for the lack of attainment of $\dot{V}O_{2\,max}$ during treadmill middle-distance running, even when race conditions are simulated, still remain to be determined.

In conclusion, pacing strategy does influence the $\dot{V}O_2$ attained in 800 m pace treadmill running in well-trained, aerobically fit middle-distance runners. Compared with constant speed running, the $\dot{V}O_2$ attained is higher for an acceleration start, and higher still for a race simulation. However, even for the race simulation 800 m pace run, the $\dot{V}O_2$ attained was only 92.5% $\dot{V}O_{2\,max}$. Reasons for the attainment of a higher $\dot{V}O_2$ in the race simulation trial are unclear at present.

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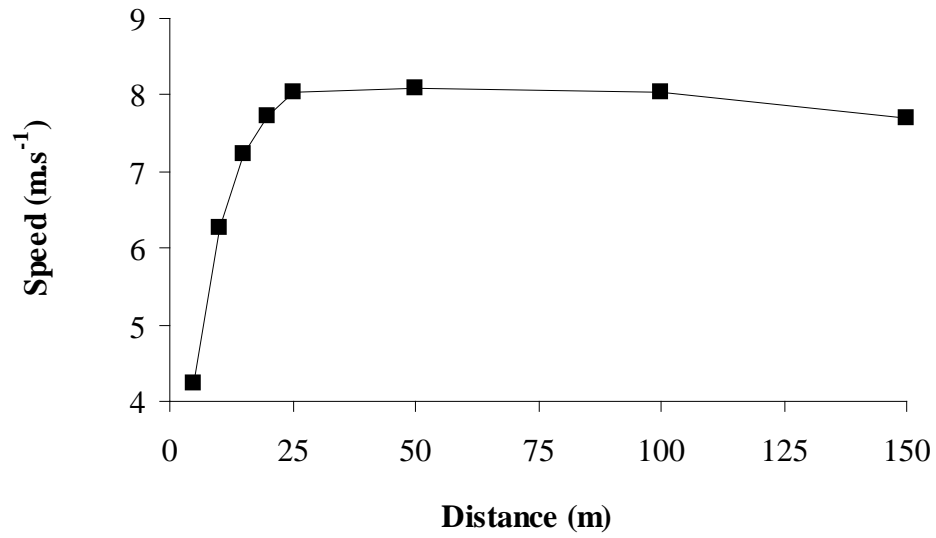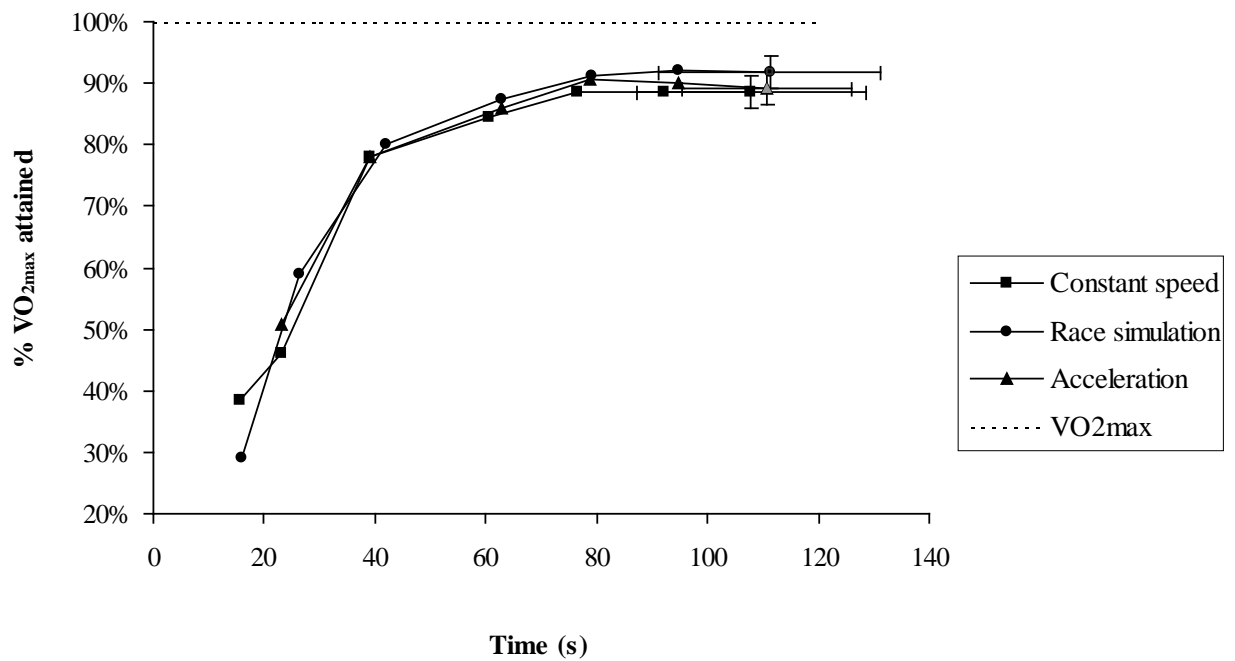
Figure 1:   **Changes in running speed with increasing distance during a simulated start to an 800 m track run (n = 6).**
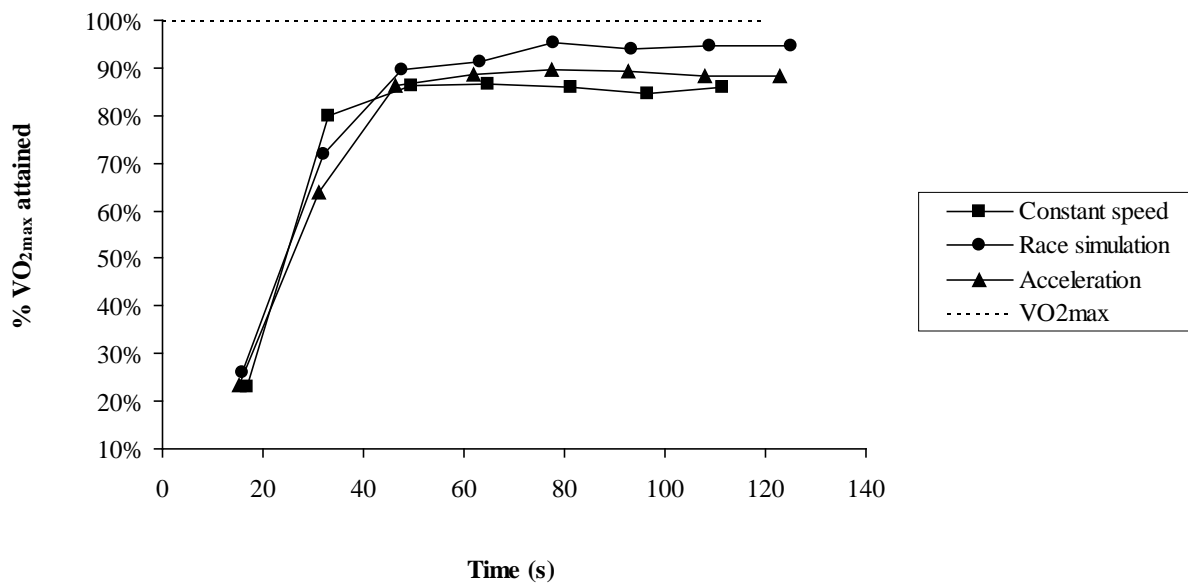
Figure 2: **% $\dot{V}O_{2max}$ attained during the constant speed, acceleration and race simulation 800 m runs in a representative subject.**

Figure 3: % $\dot{V}O_{2max}$ attained during the constant speed, acceleration and race simulation 800 m runs. For clarity error bars (representing one SD) have been omitted from all but the final data point.