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A single test for the determination of parameters of the speed-time relationship for running

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Abstract

A validated expeditious method is needed to determine critical speed (CS) and the finite distance that can be covered above CS (D'). We tested the hypothesis that a single all-out 3-min running test would accurately determine CS and D' . Seven healthy subjects completed three constant-speed runs on a treadmill for the determination of CS and D' , as well as an all-out 3-min test on a track for the determination of end-test speed (ES) and the distance above end-test speed (DES). ES ($13.4 \pm 2.8 \text{ km}\cdot\text{h}^{-1}$) was not significantly different from the speed-1/time model CS ($13.3 \pm 2.8 \text{ km}\cdot\text{h}^{-1}$). While DES ($141 \pm 34 \text{ m}$) was not significantly different from D' ($204 \pm 103 \text{ m}$), it underestimated D' in 5 of 7 subjects. Thus, the speed-1/time model CS can be accurately determined using a single 3-min test, while caution should be used in relating DES to D' .

Key Words: All-out test, critical speed, D' , running

1. Introduction

The power-time relationship defines the threshold above which maximal oxygen uptake ($\dot{V}O_{2\max}$) is elicited (critical power (CP) for cycling exercise and critical speed (CS) for running), as well as the amount of work that can be performed above CP (W') or distance that can be covered above CS (D') before fatigue terminates the exercise. This relationship has been demonstrated across the spectrum of conditioning from elite athletes (Smith et al., 1999) at the upper end, to patient populations (Neder et al., 2000) at the lower end. Further, there is building evidence that CP and CS are better predictors of exercise tolerance than the traditionally used $\dot{V}O_{2\text{peak}}$ and gas exchange threshold (GET) measurements in clinical settings (Whipp and Ward, 2009), as well as in determining athletic performance (Ade et al., 2011, Florence and Weir, 1997, Fukuba and Whipp, 1999, Jones et al., 2010, Vanhatalo et al., 2011).

The power-time relationship has been observed in cycling (Barker et al., 2006, Gaesser and Wilson, 1988, Hill et al., 1995, Housh et al., 1989, Miura et al., 1999, Miura et al., 2000, Miura et al., 2009, Neder et al., 2000, Poole et al., 1988, Poole et al., 1990, Pringle and Jones, 2002, Smith et al., 1999), rowing (Cheng et al., 2012, Hill et al., 2003, Kendall et al., 2011), knee-extension (Burnley, 2009), and running (Bull et al., 2008, Hughson et al., 1984, Smith and Jones, 2001) where a substitute for power is used when necessary. CP is associated with the muscle's aerobic power (Gaesser and Wilson, 1988, Gaesser et al., 1995, Jenkins and Quigley, 1992, McLellan and Cheung, 1992, Miura et al., 1999, Miura et al., 2000, Moritani et al., 1981, Moritani et al., 1981, Poole et al., 1990, Vanhatalo et al., 2010), while W' represents predominantly 'anaerobic' characteristics (Ferguson et al., 2007, Ferguson et al., 2010, Gaesser and Wilson, 1988, Jenkins and Quigley, 1992, Miura et al., 1999, Miura et al., 2000, Moritani et

al., 1981, Poole et al., 1990) and is determined, in part, by intramuscular energy stores of phosphate, glycogen, and oxygen (Miura et al., 1999, Miura et al., 2000, Monod and Scherrer, 1965) as well as by accumulation of fatigue-inducing metabolites (Coats et al., 2003, Ferguson et al., 2007, Fukuba et al., 2003, Jones et al., 2008). CP demarcates the heavy-severe domain boundary in that, at or below CP a general steady state is achieved (Jones et al., 2008, Poole et al., 1988), whereas above CP continuous alterations in intramuscular concentrations of phosphocreatine ([PCr]), hydrogen ion ($[H^+]$), and inorganic phosphate ([Pi]) occur, while oxygen uptake ($\dot{V}O_2$) and blood lactate ($[La^-]$) rise to maximum values (Jones et al., 2008, Poole et al., 1988). As a result, exercise above CP will lead to exhaustion or a reduction in power to an intensity \leq CP once W' has been utilized.

Traditionally the determination of the power-time relationship requires multiple constant-load tests to exhaustion at peri-maximal power outputs on different days, rendering this protocol time consuming and problematic for certain study designs (Hill, 1993). For example, intervention studies typically require a minimum of eight testing sessions per subject (Barker et al., 2006, Gaesser and Wilson, 1988, Hill et al., 1995, Miura et al., 1999, Miura et al., 2000, Miura et al., 2009, Poole et al., 1990). The development of the all-out test (Burnley et al., 2006, Dekerle et al., 2006) has led to a reduction in the number of testing sessions required to determine the parameters of the power-time relationship (Vanhatalo et al., 2007), directly addressing the time consuming dilemma. The theoretical basis for the all-out test is in accordance with the mathematical description of the power-time relationship, i.e., upon depletion of W' the remaining maximally sustainable power output must be equivalent to CP (Vanhatalo et al., 2007). Indeed, Vanhatalo et al. (2007) found that the end-test power (average power output over final 30 s) and the work above end-test power for a single 3-min cycling test can accurately

determine CP and W' respectively. The all-out test has since been utilized for several other cycling studies (Parker Simpson et al., 2012, Vanhatalo and Jones, 2008, Vanhatalo et al., 2008, Vanhatalo et al., 2010, Vanhatalo et al., 2011), as well as adapted for knee-extension exercise (Burnley, 2009) and rowing (Cheng et al., 2012).

Recently, Pettitt et al. (2012) utilized a 3-min all-out running test to predict outdoor racing performance. The aim of this study, however, was not to examine the validity of the 3-min test parameters. Therefore, to date no study has directly assessed the accuracy of parameter estimation from a 3-min running test compared to the traditional determination of CS and D' . This assessment accuracy is critical as it cannot be directly implied from the 3-min cycling test due to the inherently higher degree of variability within the 3-min running test as a result of differences in track versus treadmill running and changing gait patterns that might vary the relationship between speed and actual muscular work.

Therefore, the purpose of the present study was to determine if a single all-out running test could be used to accurately determine CS and D' . Specifically we tested the hypotheses that, for a 3-min all-out running test: (1) the end-test speed (ES) would not differ significantly from CS determined with the traditional protocol; and (2) the distance above end-test speed (DES) would not differ significantly from D' determined with the traditional protocol.

2. Methods

2.1. Subjects

Seven healthy subjects (4 men and 3 women, mean \pm SD; age 25.3 ± 3.4 years, body mass 69.7 ± 13.7 kg, height 174.1 ± 11.3 cm) volunteered to participate in this study. Subject fitness classification ranged from not active to highly trained (< 150 min marathon). The study

was approved by the Institutional Review Board of Kansas State University, Manhattan, KS, and conformed to the declaration of Helsinki. Prior to testing, subjects were informed of the overall protocol, along with the potential risks and benefits involved and provided written informed consent. Subjects were instructed to abstain from vigorous activity for 24 hours prior to testing and not to consume caffeine three hours prior to testing. Each subject reported to the Human Exercise Physiology Laboratory eight times with at least 24 hours between adjacent testing sessions.

2.2. Equipment Calibration

Prior to beginning the study, the treadmill (Quinton Brute Q55XT Sport, Bothell, WA, USA) was calibrated across the expected range of speeds for the running sessions. Pulmonary gas exchange ($\dot{V}O_2$, expired carbon dioxide ($\dot{V}CO_2$)) and ventilation (\dot{V}_E) were measured breath-by-breath during the incremental test, the $\dot{V}O_{2max}$ validation test, and the runs above and below CS using a metabolic measurement system (CardiO2, Medical Graphics Corp., St. Paul, MN, USA). Prior to each testing session, the gas analyzers were calibrated using gases of known concentration spanning the expected range of inspired and expired values, while the flow transducer was calibrated at different flows with a 3.0 l syringe. The accelerometer (RS800CX, Polar Electro Inc., NY, USA) was calibrated for each subject to the manufacturer's specifications using the constant-speed runs on the treadmill at a 1% grade, which on average was 99.2% (range 92.7 – 104.4%) of actual running speed.

2.3. Incremental Test to Volitional Exhaustion

The incremental protocol used for the determination of $\dot{V}O_{2\max}$ and the speed at $\dot{V}O_{2\max}$ (S_{peak}) was adapted from Smith and Jones (2001). The protocol began with an initial speed of 8 – 10 $\text{km}\cdot\text{h}^{-1}$ (depending upon the reported level of fitness from the subject) at a fixed incline of 1%. The speed was increased by 0.5 $\text{km}\cdot\text{h}^{-1}$ every three min until the subject achieved 95% estimated maximal heart rate ($220 - \text{age}$). At this point, the speed was reduced by 1 $\text{km}\cdot\text{h}^{-1}$ and the treadmill grade was increased 1% every 60 s until volitional exhaustion. Oxygen consumption ($\dot{V}O_2$) and speed were averaged over the final min of each three min stage leading up to 95% maximal heart rate. The speed from each stage up to 95% maximal heart rate was then plotted against the corresponding $\dot{V}O_2$ and linearly extrapolated to S_{peak} using the subject's $\dot{V}O_{2\max}$. Validation of $\dot{V}O_{2\max}$ was accomplished during the 110% S_{peak} constant speed run. $\dot{V}O_{2\max}$ was considered valid if the highest $\dot{V}O_2$ obtained on the secondary test was less than 0.2 $\text{l}\cdot\text{min}^{-1}$ greater than that on the incremental max test (Poole et al., 2008). If a difference was observed (occurred 2 times within this study), a second validation test was completed at $\sim 120\%$ S_{peak} , after which $\dot{V}O_{2\max}$ and S_{peak} were adjusted accordingly.

2.4. Traditional Determination of the Speed-Time Relationship

For the determination of the speed-time relationship, each subject completed three randomly ordered constant speed runs to exhaustion on a treadmill at speeds spanning 90 – 120% S_{peak} designed to induce exhaustion within 2 – 10 min (Poole et al., 1988). These runs took place on a treadmill set at a grade of 1%, previously demonstrated to most accurately reflect outdoor running (Jones and Doust, 1996). Subjects initiated each testing session with 5 min of walking at

a speed of $5 \text{ km}\cdot\text{h}^{-1}$. After this, the subject straddled the treadmill belt as it was brought up to the correct speed. At that time, the subject ran onto the moving belt from above using a handrail for stabilization. The elapsed time of each test was recorded to the nearest s from when the subject ran onto the treadmill belt until the time when the subject grasped the handrail, signaling exhaustion. Throughout these tests, investigators provided strong verbal encouragement as motivation. The resulting time-to-exhaustion data were then fit to the two-parameter linear speed-1/time model:

$$S = (D'/t) + CS \quad (\text{Equation 1})$$

for the determination of CS and D' (Hill, 1993, Poole et al., 1988, Whipp et al., 1982), where S represents speed, t represents time-to-exhaustion, CS represents critical speed, and D' represents the finite distance that can be covered above CS. The 1/time model has commonly been utilized for parameter determination (Brickley et al., 2002, Ferguson et al., 2007, Ferguson et al., 2010, Pringle and Jones, 2002)

2.5. Validation of Critical Speed

On subsequent days, subjects completed a run slightly above and a run slightly below CS using the same protocol as the previous constant speed tests, running to exhaustion or 15 min (when the test was terminated). Previous authors have described responses to exercise at intensities slightly above or below CP (Burnley et al., 2012, Jones et al., 2008). If the $\dot{V}O_2$ achieves a steady state below CS, but continually rises above CS, this implies that the threshold above which $\dot{V}O_{2\text{max}}$ can be elicited (CS) lies within this interval, thus increasing confidence in the estimated parameter.

2.6. Single Test for the Determination of the Speed-Time Relationship

For ease of comparison with CS determined from treadmill testing, speed will be used in place of velocity for the track protocol, as speed is of concern not the vector quantity of velocity *per se*. From pilot data in our laboratory, it was observed that running speed plateaued over the final 20 s of a 3-min all-out running test on an outdoor track. Therefore, we concluded 3 min would provide adequate time for a plateau in speed to be obtained. All subjects completed an initial 3-min run that served as a familiarization test prior to the test used for data analysis. For the 3-min test, subjects began by warming-up on a track with light jogging and walking at speeds that would not begin to continually utilize D' (i.e., below CS). The test was initiated from a stationary position and the subjects were instructed to run as fast as possible throughout the entire test, even though speed would decline after achieving initial peak values. Strong verbal encouragement was provided throughout the test and subjects had no feedback about elapsed time, to prevent pacing. The subject's speed during the 3-min test was recorded second-by-second using an accelerometer positioned on the right foot (RS800CX, Polar Electro Inc., NY, USA), calibrated as previously mentioned. ES was determined using the average speed over final 20 s of the 3-min run, while DES was determined from the area under the speed curve above ES (Figure 1).

2.7. Data Analysis

The breath-by-breath data collected during the incremental $\dot{V}O_{2\max}$ test was first converted into 15 s intervals and time-aligned to the start of incremental exercise. $\dot{V}O_{2\max}$ was

defined as the highest 15 s value during the incremental test, validated as previously mentioned. The breath-by-breath data were then converted into 30 s averages and used in the plot of speed vs. $\dot{V}O_2$ for determination of S_{peak} . The data from the constant speed runs were analyzed with commercial software (SigmaPlot 10.0, Systat Software Inc., CA, USA) using the speed-1/time model for the determination of CS and D' . Heart rate was monitored beat-by-beat during all tests with a heart rate monitor (RS800CX, Polar Electro Inc., NY, USA).

2.8. Statistical Analyses

Comparisons of parameters between the speed-1/time model and 3-min test were made using paired t-test analyses, while Pearson product moment correlations were used to examine the relationships. Statistical significance was accepted at a level of $P < 0.05$ and the results are presented as mean \pm SD.

3. Results

3.1. Incremental Test

Group mean values for $\dot{V}O_{2\text{max}}$ and S_{peak} were $3.45 \pm 0.72 \text{ l}\cdot\text{min}^{-1}$ ($49.6 \pm 5.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and $15.1 \pm 2.7 \text{ km}\cdot\text{h}^{-1}$, respectively.

3.2. Speed-Time Relationship

Time-to-exhaustion during the three constant speed runs averaged $199 \pm 88 \text{ s}$, $323 \pm 118 \text{ s}$, and $511 \pm 62 \text{ s}$. Figure 1 demonstrates the use of speed-1/time model in determining CS and D' for an individual subject, while CS and D' values for each subject are presented in Table 1.

The data displayed a linear fit ($r^2 = 0.98 \pm 0.01$) for all subjects. The standard errors as a percent of the parameter estimates for CS and D' were $2.4 \pm 1.1\%$ and $11.9 \pm 5.0\%$ respectively.

3.3. Runs Above and Below CS

Figure 2 depicts a representative subject's $\dot{V}O_2$ data and the mean $\dot{V}O_2$ data for the runs above and below CS, respectively. Speeds were $12.5 \pm 6.7\%$ above and $5.4 \pm 1.4\%$ below CS ($14.0 \pm 3.0 \text{ km}\cdot\text{h}^{-1}$ and $11.6 \pm 2.7 \text{ km}\cdot\text{h}^{-1}$, respectively). Subjects achieved a significantly higher $\dot{V}O_{2\text{peak}}$ for the run above CS ($3.3 \pm 0.7 \text{ l}\cdot\text{min}^{-1}$, $97.4 \pm 5.1\% \dot{V}O_{2\text{max}}$) compared to the run below CS ($2.9 \pm 0.6 \text{ l}\cdot\text{min}^{-1}$, $86.5 \pm 4.3\% \dot{V}O_{2\text{max}}$). The $\dot{V}O_{2\text{peak}}$ for the run above CS was not statistically different from the $\dot{V}O_{2\text{max}}$ during the incremental test to volitional exhaustion, while the $\dot{V}O_{2\text{peak}}$ for the run below CS was significantly lower than $\dot{V}O_{2\text{max}}$. No subject was able to complete 15 min during the run above CS ($641 \pm 230 \text{ s}$, range 228 – 885 s), while every subject was able to complete 15 min during the run below CS. $\dot{V}O_2$ was not statistically different from 180 s to end exercise during the run below CS, indicating the attainment of a steady state (Figure 2).

3.4. 3-min Test

Consistent with our pilot data, the mean speed was not significantly different at 160 s vs. 180 s, indicating the subjects' speed had plateaued as expected. Figure 1b depicts a representative 3-min test in one subject, while the individual and mean data are presented in Table 1. The 3-min ES was not significantly different from CS and DES was not significantly

different than D' , despite the strong tendency to underestimate D' (Table 1). The relationships between parameters are shown in Figure 3.

4. Discussion

The major finding of the present study, consistent with our first hypothesis, is that the 3-min all-out running test accurately predicted CS determined from the speed-1/time model. Also consistent with our second hypothesis, the 3-min all-out running test DES was not significantly different than the speed-1/time D' . However this must be taken with caution as DES underestimated D' in 5 of 7 subjects.

To ensure accuracy in CS and D' it is recommended that the standard error estimates for each parameter are $< 5\%$ with the use of the speed-1/time model (Hill, 1993). In the present study, all standard error estimates were below these recommended values for CS, thus increasing confidence in the accuracy of this parameter estimate. However, the standard error estimates for D' were above the recommended value, which may have contributed to the discrepancy between D' and DES. Furthermore, confidence was increased in the estimate of CS with the use of tests above and below CS. The fact that a steady state in $\dot{V}O_2$ was achieved and every subject completed 15 min of exercise below CS, while $\dot{V}O_2$ was driven to its maximum value and exercise duration was markedly limited above CS (Figure 2) validated that the threshold for attainment of $\dot{V}O_{2max}$ (therefore CS) lay within these limits (Poole et al., 1988).

Previous investigations evaluating a single all-out test have utilized different test durations depending upon the mode of activity. For cycling, 3-min is adequate time to allow for the complete depletion of W' and a leveling off in power output equal to CP (Burnley et al.,

2006, Vanhatalo et al., 2007). It has recently been demonstrated that 3-min is also adequate time for an all-out rowing test (Cheng et al., 2012). However, for knee-extension exercise the all-out test needs to be extended to 5-min in order to allow for the complete depletion of W' (Burnley, 2009). Prior to this study, pilot data collected from our laboratory suggested that 3-min was adequate to allow for the complete depletion of D' and for the speed to level off at/near CS during an all-out running test.

According to the speed-time relationship, D' is utilized at intensities greater than CS until it is consumed making these intensities no longer sustainable. The duration that this exercise can be maintained is dependent upon the magnitude of D' , which is determined by available energy stores and their rate of depletion (Jones et al., 2008, Miura et al., 1999, Miura et al., 2000), as well as the accumulation of fatigue-inducing metabolites (Coats et al., 2003, Ferguson et al., 2010, Fukuba et al., 2003, Jones et al., 2008). In accordance with this, the 3-min test should deplete these stores and accumulate resultant metabolites, and the distance required to do so (DES) should be equivalent to D' . In the present study DES underestimated D' by 31% despite not being statistically different (Table 1; Figure 3). This underestimation of D' is likely influenced by the larger standard error associated with D' than with CS, differences between the treadmill tests and the 3-min test, and whether distance is the equivalent of work from the power-time relationship (see below). However, this underestimation of D' is consistent with previous reports in which there was high variability between the work above end-test power and W' (Burnley, 2009, Cheng et al., 2012).

Several plausible explanations may account for the discrepancy between DES and D' . There is a higher metabolic demand with forward propulsion on the track, due to overcoming air resistance and inertia, compared to running on the treadmill at the same speed. However, a 1%

grade was utilized on the treadmill to address this issue (Jones and Doust, 1996). During the 3-min test subjects overcame a substantial amount of inertia while accelerating, which was not present during the treadmill tests. This requires additional energy (as D') above that necessary to sustain a constant speed, and has been estimated to represent 20-25% of the total energy dissipated during a 100 m sprint (Arsac and Locatelli, 2002). Therefore, D' measured as a distance may not be entirely representative of the 'actual' work the muscles are performing. However, measuring the work of running is problematic due to the variability in stride mechanics throughout a test and as fatigue ensues. As it is, it may be appropriate to 'correct' the value of DES by adding in the additional energy utilized to overcome this inertia (if it can accurately be determined) and/or reducing the influence of inertia by initiating the test from a jog (below CS). During the turns on the track speed could have been altered, however this was not the case as speed was well maintained through the turns. The 3-min test is dependent upon a sustained maximal effort by the subject, and if maximal effort is not put forth throughout the test this would lead to an over- or underestimation of parameter estimates. Potentially, gait patterns (i.e., stride length, stride frequency, contact time, etc.) may have differed between the treadmill and track tests, also leading to differences in 'actual' muscular work vs. speed. Alternatively, the fact that the 3-min running test is performed on a track under similar conditions to locomotion it may in fact yield a DES value closer to a 'true' D' (i.e., improve ecological validity), which may be overestimated by the D' from the treadmill tests. Further research is needed to investigate this discrepancy and determine possible solutions to equate DES with D' .

The speed-time relationship is a major determinant and predictor of endurance performance (Florence and Weir, 1997, Fukuba and Whipp, 1999, Housh et al., 1989), as it characterizes the maximum steady states for $\dot{V}O_2$ and perturbation of pH, [Pi] and [PCr] (Jones et

al., 2008, Poole et al., 1988). In support of this, CS has been shown to occur in close proximity to maximal lactate steady state (MLSS) (Smith and Jones, 2001). Thus, CS and MLSS represent a threshold above which exercise duration is severely limited and can be predicted based upon CS and D' . Vanhatalo et al. (2010) demonstrated that, at exhaustion [PCr], pH, and [Pi] achieved similar concentrations over a range of different work rates in the severe domain. These findings suggest that at exhaustion, critical concentrations might exist for these compounds which reflect the depletion of W' (and presumably D'). Ferguson et al. (2010) have recently shown that following exhaustive exercise, $\dot{V}O_2$ (indicative of [PCr]) recovered prior to W' restoration, while arterial lactate remained elevated after W' restoration. The authors interpreted this finding as suggesting that W' is not determined solely by PCr stores, arterial lactate, or a depletable finite energy store in isolation. Despite the elusive defining mechanisms, the speed-time relationship is one of, if not, the most informative characterization(s) of performance.

The availability of a single test to determine the parameters of the speed-time relationship would facilitate use of the relationship by reducing the number of testing sessions necessary, as the all-out test has done for other modes of exercise (Burnley, 2009, Cheng et al., 2012, Vanhatalo et al., 2007). For example, a single test would be more practical in the athletic arena, so as to minimize any disruption to a training schedule. In addition, prediction times for a given distance or speed can be determined with the parameters from the 3-min running test; however the current frequent underestimation of D' by DES (despite no statistical difference) would lead to inconsistent prediction times. For example, using the group mean values, running at $15.0 \text{ km}\cdot\text{h}^{-1}$ would induce exhaustion at $\sim 432 \text{ s}$ based on the speed-1/time model and $\sim 317 \text{ s}$ based on the 3-min test. If D' can be more accurately estimated with the 3-min running test, in theory a

runner's best time can be determined for any given running event lasting between ~2 and 10 min using a single 3-min test.

In summary, ES determined from the 3-min all-out running test was not significantly different from the speed-1/time model CS. DES from the 3-min all-out running test was also not significantly different than the speed-1/time model D' , however this must be taken with caution as DES frequently underestimated D' . The findings of the present study demonstrate a single 3-min running test (with no need for prior $\dot{V}O_{2\max}$ test) can be used to determine CS. Thus, the previous work of utilizing an all-out test can be utilized for CS, but caution is warranted for D' .

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Figures

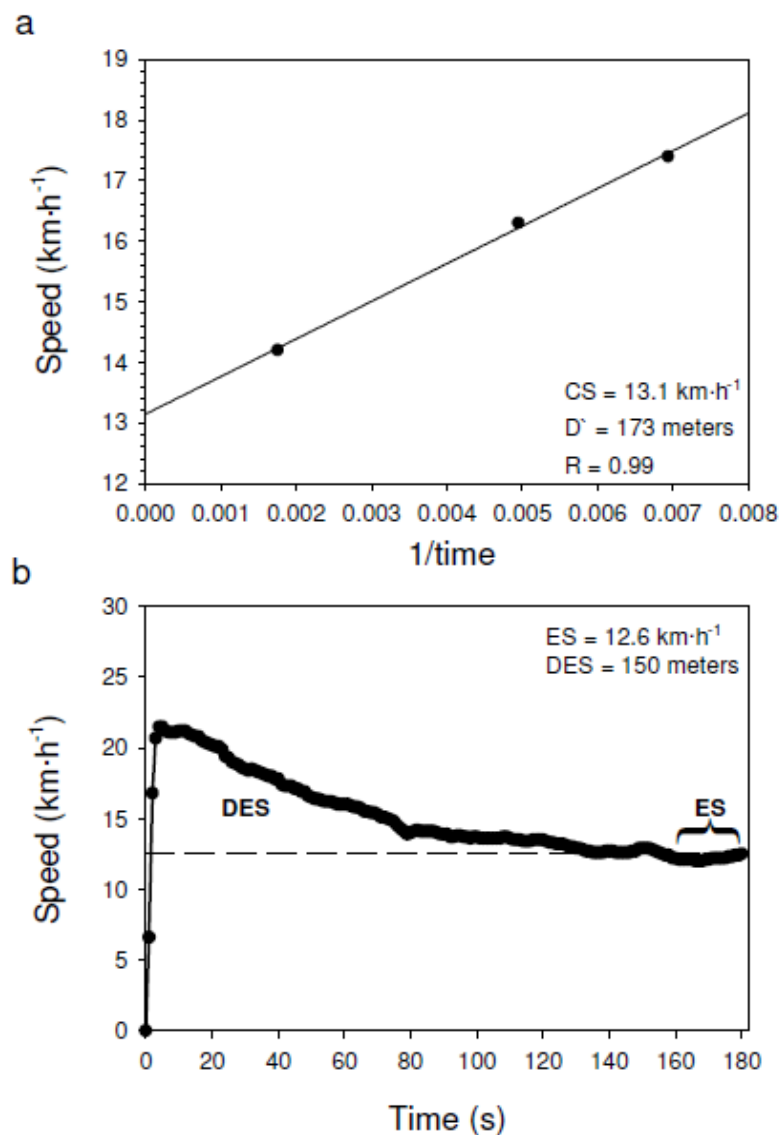


Figure 1 Parameter estimation for a representative subject: a. Linear speed-1/time model with data from constant-speed runs on a treadmill. CS was determined as the y-intercept and D' as the slope. b. Second-by-second data from the 3-min all-out run on a track with the average speed over the last 20 s defined as end-test speed (ES), and the area under the curve representing the distance covered above end-test speed (DES).

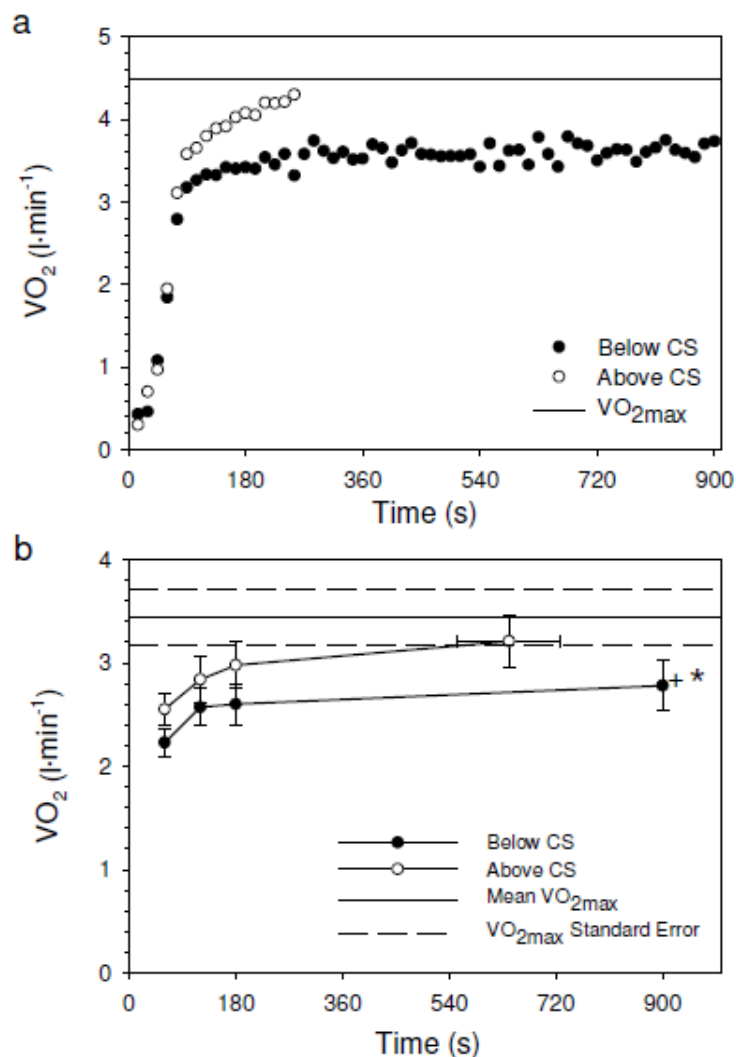


Figure 2 Oxygen uptake response for the above and below CS runs: a. Representative subject ran for the entire 15 min during the run below critical speed (CS) at $16.9 \text{ km} \cdot \text{h}^{-1}$, but could not complete 15 min for the run above CS at $20.4 \text{ km} \cdot \text{h}^{-1}$. b. Mean data for the runs above and below CS. + significantly lower than the $\dot{V}O_{2\text{max}}$ from incremental test to volitional exhaustion ($P < 0.05$). * significantly lower than end-exercise $\dot{V}O_2$ for the above CS run ($P < 0.05$). There was no difference in $\dot{V}O_2$ between 180 s and 15 min in the run below CS, indicating the attainment of a steady state.

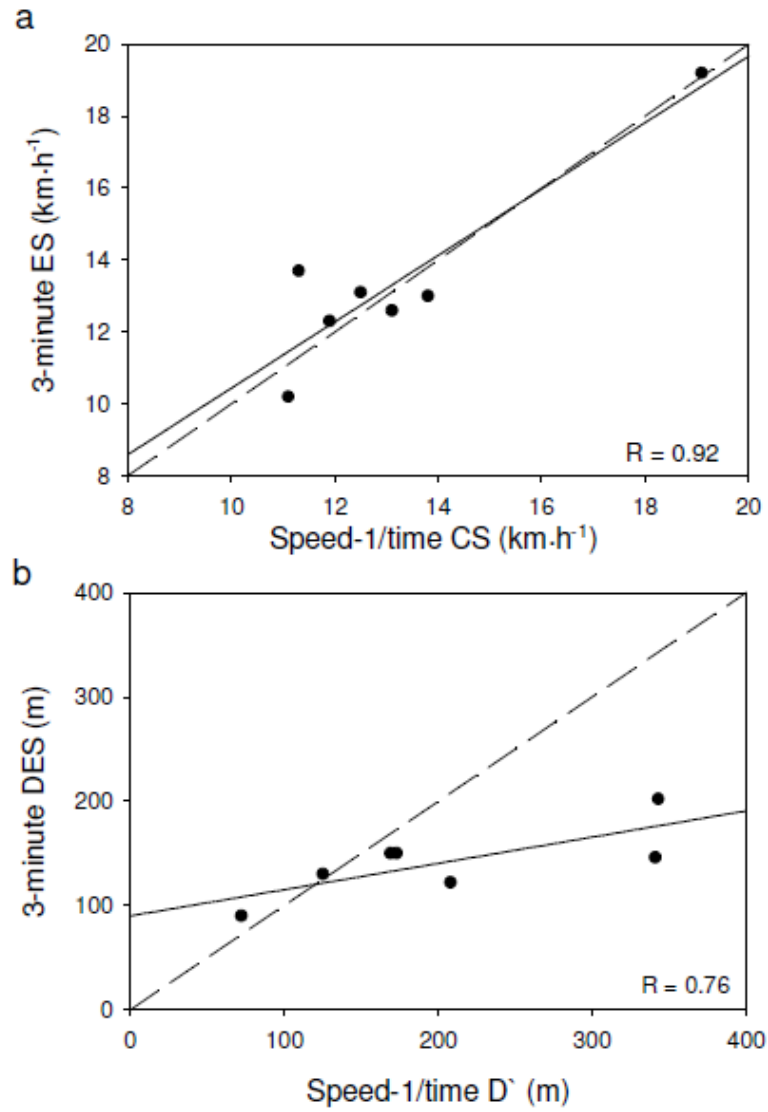


Figure 3 Comparisons among determinants between tests: a. 3-min ES vs. speed-1/time model CS. 3-min DES vs. speed-1/time D`. Line of identity shown as dashed line.

Table 1

Subject	Speed-1/time		3-min Test	
	CS (km·h ⁻¹)	D` (m)	ES (km·h ⁻¹)	DES (m)
1	12.5	125	13.1	130
2	13.8	169	13.0	150
3	11.1	341	10.2	146
4	13.1	173	12.6	150
5	11.9	343	12.3	202
6	19.1	72	19.2	90
7	11.3	208	13.7	122
Mean	13.3	204	13.4	141
SD	2.8	103	2.8	34

Table 1. Speed-1/time and 3-minute model parameters. CS = critical speed, D` = the finite distance above CS, ES = end-test speed, DES = distance above end-test speed.