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The British Association of Sport and Exercise Sciences Guide

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Chapter 4.1

Middle- and long-distance running

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The middle- and long-distance running events comprise the 800m, 1500m, 3000m steeplechase, 5000m, 10,000m and marathon. Although these events are described as race distances, it is useful for the physiologist to consider running duration, which will differ between athletes dependent on ability, age, and sex (March et al., 2011), highlighted in Figure 1. For both middle- and long-distance running the aerobic system is the predominant contributor to energy turnover, with the proportion of energy from anaerobic sources decreasing as distance run increases (Spencer and Gastin, 2001). However, the absolute contribution of anaerobic energy might not differ greatly in well-trained athletes, especially over the shorter distances (Gastin, 2001).

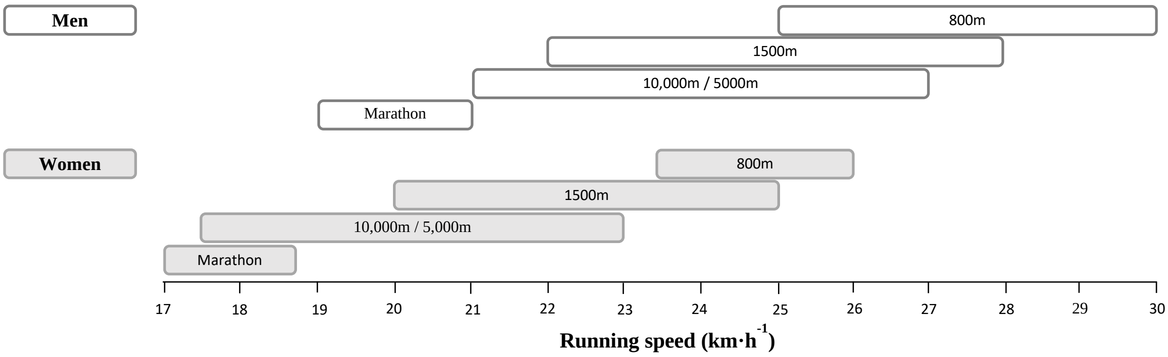

Figure 1 – The range of running speeds found in men's and women's middle- and long-distance championship racing (based on data from Hettinga et al., 2019).

Physiological testing is used to measure and monitor an athlete's adaptation to training across a season/their career, notwithstanding that the best test of progression is still performance in their event itself. However, the tactical nature of racing means that there is often a disconnect between an athlete's physiological capacity and their race performances; indeed, athletes do not need to even run their season's best time to win at major championships (Hanley and Hettinga, 2018). Further, as a given athlete is not always able to control the pace of a race, it is important they develop a range of physical qualities to maximise their competitive advantage in any given situation. It is clear athletes do not prepare for competition by repeatedly running the race distance; instead, training focuses on adapting to different demands of the event, including aerobic and anaerobic metabolism. Therefore, any physiological testing should take into consideration the measurement of the important contributors to fast running within the context of the race demands.

The following tests can be used to profile different physiological metrics across a distance runner's profile, shown in Figure 2, with normative data provided to facilitate the interpretation of results in Table 1. These include physiological assessments made in a laboratory, and field-based assessments of performance metrics that can be used effectively when laboratory access is limited. For inexperienced athletes, general benchmarking of all factors can be effective in identifying the potential strengths and opportunities, that can in turn inform training. For more experienced or elite athletes with a greater history of testing, the testing battery should be refined with appropriate metrics assessed to inform key performance questions in different phases of the season.

Laboratory assessments

Laboratory assessments are used to profile the aerobic physiology of a runner. A two-phase test has been formulated to assess the primary physiological determinants of endurance running, namely lactate thresholds, running economy (RE) and maximal oxygen uptake ($\dot{V}O_2max$), in one visit and with only one phase of maximal running (Jones, 2007). Separately, an assessment of $\dot{V}O_2$ on-kinetics can also be conducted.

Phase one– submaximal aerobic assessment

After a 10-min warm up (1 km·h^{-1} lower than starting speed), a multi-stage discontinuous incremental test on a treadmill is completed, with 3-min stages of running interspersed by 30-s rest to obtain blood measures. For trained runners, stages are set to 3 min to obtain a steady state response in the moderate and heavy exercise domains (Shaw et al., 2013), with increments moving from moderate to heavy and into severe exercise within 6-9 stages (typically 0.5-1 km·h^{-1} dependent on existing knowledge of the athlete's thresholds and the sensitivity required). The treadmill gradient is set to 1% to replicate the metabolic cost of outdoor running (Jones and Doust, 1996), although practitioners who are concurrently taking biomechanical measures should note the potential effect on gait parameters. The starting speed is set so that the athlete could maintain that pace for >3 h and comfortably hold a conversation, derived by exploring the typical paces used by the athlete in training. Heart rate and pulmonary gas exchange is monitored throughout the assessment, with blood [lactate] (via capillary earlobe samples) and rating of perceived exertion (RPE) assessed during rest intervals. Tests should be terminated the stage before the athlete would reach exhaustion, with blood [lactate] typically >5 mM and heart rates within 10 b·min^{-1} of maximum. This phase of the test can be repeated every 10-12 weeks throughout the season to monitor progression and inform appropriate training paces (Figure 2) and is used to calculate the following variables.

Blood lactate thresholds and the fractional utilisation of $\dot{V}O_2max$

Lactate threshold is identified as the sustained increase in blood [lactate] above baseline values. As outlined in previous chapters, this metric represents the boundary between the moderate and heavy domain (Figure 2). The lactate turnpoint (LTP) is the second lactate threshold, defined as a distinct 'sudden and sustained' breakpoint in blood [lactate], and is typically identified as a change in blood [lactate] >1 mmol·L^{-1} between stages (Figure 2). The LTP occurs below the heavy-severe boundary, representing an intensity that can be sustained for ~60 min. Consequently, LTP is used to define the transition between steady and tempo running in distance runners, an important element of world-class athletes' training (Casado, Hanley and Ruiz-Pérez, 2020).

Although both LT and LTP are commonly expressed as a speed threshold ($km \cdot h^{-1}$), it is important to note this expression is a composite of the lactate thresholds and RE. The $\dot{V}O_2$ at LT and LTP can also be expressed relative to $\dot{V}O_2max$, providing the fractional utilisation of $\dot{V}O_2max$ and therefore a measure of sustainable energetic rate rather than running speed. As changes in the $\dot{V}O_2max$ of an experienced athlete can be small (Jones, 2006), the ability to use as much of the aerobic capacity as possible at either the LT (marathons) or LTP (half marathons or 10,000m) is an important target, especially for long-distance runners.

Running economy

RE is commonly expressed as the oxygen cost of running, combining the energetic cost of running and the substrate utilisation of an athlete into one variable, calculated as the average $\dot{V}O_2$ over the four stages below LTP, and expressed as $mL \cdot kg^{-1} \cdot km^{-1}$ to enable inter- and intra-individual comparisons (Shaw, Ingham and Folland, 2014). As the expression is a cost, a lower value is better for RE (Table 1). To facilitate interpretation of RE, the underlying energetic cost should still be calculated to assess changes that are independent of substrate utilisation, using the following equations combining updated non-protein respiratory quotient equations (Péronnet and Massicotte, 1991) and the energy equivalents for the substrates metabolised at moderate-high intensities (Jeukendrup and Wallis, 2005):

Total energy cost ($Kcal \cdot min^{-1}$)=

$$(((1.695\times\dot{V}O_2)–(1.701\times\dot{V}CO_2))\times9.75)+(((4.585\times\dot{V}CO_2)–(3.226\times\dot{V}O_2)\times4.07)$$

Relative energy cost ($Kcal \cdot kg^{-1} \cdot km^{-1}$)=(Total energy cost/BM)/(Speed $km \cdot h^{-1}$/60)

Although RE has been shown to be a key determinant in both long- and middle-distance athletes, it should be noted that the measurement of RE from pulmonary gas exchange limits its assessment to submaximal intensities and therefore is more relevant for performance in long-distance running. As RE is known to change with running speed (Shaw, Ingham and Folland, 2014), extrapolations to the maximal/supra-maximal intensities of middle-distance events should be made with caution.

Phase two – maximal aerobic assessment

The second phase of the treadmill testing is a maximal aerobic assessment. After ~15 min of rest/active recovery after the submaximal assessment, the athlete completes a continuous ramp test. The submaximal assessment can be used to infer an appropriate starting speed, typically set 2 $km \cdot h^{-1}$ lower than the final increment in phase one. After 1 min to allow the athlete to settle into the pace, speed is increased by 0·5 km.h^{-1} until volitional exhaustion, demonstrated by the athlete being unable to maintain their position at the front of the treadmill despite encouragement, or the athlete placing their hands on the rail and straddling the belt. Heart rate and pulmonary gas exchange are monitored throughout, with blood [lactate] assessed on completion of the test and repeated every minute until blood [lactate] begins to fall to obtain peak blood [lactate]. This phase is used to calculate the metrics below.

$\dot{V}O_2max$

$\dot{V}O_2max$ remains a key a key physiological determinant for both middle- and long-distance runners. An athlete's $\dot{V}O_2max$ can be combined with RE to calculate the velocity at $v\dot{V}O_2max$, typically calculated by the following equation:

$$v\dot{V}O_2max = (\dot{V}O_2max \times 60)/RE$$

Where $v\dot{V}O_2max$ is in km·h^{-1}, $\dot{V}O_2max$ in mL·kg^{-1}·min^{-1} and RE in mL·kg^{-1}·km^{-1}.

Although $v\dot{V}O_2max$ calculated from $\dot{V}O_2max$ and RE has shown strong associations with endurance running performance, its use to demarcate the upper boundary of the severe domain is less established and appears to underestimate this threshold (Figure 2), especially in well-trained athletes with fast $\dot{V}O_2$ on-response times.

Table 1 – Typical values for Running economy (RE) in oxygen cost, Lactate threshold (LT) lactate turnpoint (LTP), maximal oxygen update ($\dot{V}O_2max$) and maximal sprint speed (MSS) in endurance runners based on testing of UK athletes.

	Females					**Males**				
	RE	**LT**	**LTP**	**$\dot{V}O_{2max}$**	**MSS**	**RE**	**LT**	**LTP**	**$\dot{V}O_{2max}$**	**MSS**
World Class	<185	>18	>20	>70	>9.0	<185	>19	>22	>80	>10
Good	185-204	17-18	18-20	60-69	8.2-9.0	185-204	18-19	20-22	70-79	9.2-10
Moderate	205-220	15-17	17-18	50-59	7.5-8.1	205-220	16-18	18-20	60-69	8.5-9.1
Low	>220	<15	<17	<50	<7.5	>220	<16	<18	<60	<8.5

Application to training

The results from both phases of the test can be used to inform appropriate training zones, shown in figure 2 (Jones 2007). In addition, results from phase 1 can be used to calculate equivalent heart rate zones for easy, steady and tempo running. As heart rate provides an index of internal load, these zones can be effective for guiding training intensity on different terrains (off road, hills etc) or in extreme environments (heat or altitude), accounting for the additional load an athlete might experience for a given running speed.

$\dot{V}O_2$ on-kinetic assessment

On a separate laboratory visit, the following protocol can be used to assesses the $\dot{V}O_2$ on-kinetics in both the moderate and severe exercise domains, based on procedures outlined by Carter et al. (2002). Upon arrival, a light warm up can be conducted, but kept at a speed <80% of LT. Athletes then straddle the treadmill belt, with baseline $\dot{V}O_2$ data captured for 2 min. In this time, the belt is set to an appropriate speed, initially 90% LT. At 2 min, the athlete is instructed to drop onto the treadmill belt and begin running for 6 min, with the precise time matched with the $\dot{V}O_2$ data collection to identify this transition in the analysis. This bout provides assessment of $\dot{V}O_2$ phase II responses in the moderate domain with no priming effect on the following bout. Athletes then rest for 10 min, before returning to the treadmill and repeating the above procedure with the treadmill speed set to 80% of the difference (Δ) between LT and v$\dot{V}O_2$max to assess the $\dot{V}O_2$ phase II responses, in addition to the $\dot{V}O_2$ slow component, in the severe domain. It is this section that is of greatest relevance to middle and middle/long distances, given these events occur in the severe domain. Data can then be modelled using non-linear regression techniques, as outlined in previous chapters.

This assessment can be used to monitor chronic adaptions, but also acute priming activities that are used before competitive performances (i.e., warm-ups and nutritional priming). When assessing warm-ups for events that are performed at intensities >CS, the initial moderate domain bout should be replaced with the event priming routine, with appropriate focus on the timing of the priming routine relative to the exercise bout that mimics the competition timeline.

Field-based performance testing

Critical speed (CS) and D'

As discussed in detail in previous chapters, maximal running trials can be used to calculate the boundary between the heavy and severe domains, CS, and the ability to operate above this boundary, D' (Hughson, Orok and Staudt, 1984). Efforts are typically performed as time to complete a set distance, given an athlete's familiarity with such efforts from racing. The model requires at least three different race times with the longest and shortest differing in duration by ~10 min (1500m, 3000m and 5km from races; or 1200m, 2400m and 4000m for prescribed training efforts). As this requires only a stopwatch and a track to complete, this can be an effective monitoring tool for those without laboratory access.

For a valid assessment of CS and D', performance trials must be truly maximal. Races should be included only where the goal is the shortest duration for the given distance, rather than tactical races that prioritise finishing position. Though attempts have been made to combine multiple trials into one visit to enable efficient assessment of CS and D', it has been shown that athletes do not achieve truly maximal performances when compared with exhaustive trials on separate days, leading to inaccurate D' values that do not reflect an athlete's true capacity (Galbraith et al., 2014). Finally, given that the athlete's physiology needs to be uniform through all assessments to calculate a true CS and D', efforts conducted >4 weeks apart should not be combined into the same model, especially where training focus and targeted race distances have changed.

Maximal sprint speed (MSS)

Maximal sprint speed (MSS) can be assessed on a 50m straight on a running track. After a thorough warm-up and strides, athletes maximally accelerate through the first 20m and aim to at least achieve and maintain their maximum speed for the following 30m. Laser radars enable assessment of velocity throughout, where MSS is defined as the maximum velocity from the radar trace. Timing gates can be used where radar is not accessible, spaced at 10m intervals from 20m onwards, with the maximum velocity over 10m as an index of MSS. The MSS can also be used in conjunction with v$\dot{V}O_2$max to calculate the anaerobic speed reserve (ASR), defined as the difference between these values (Blondel et al., 2001).

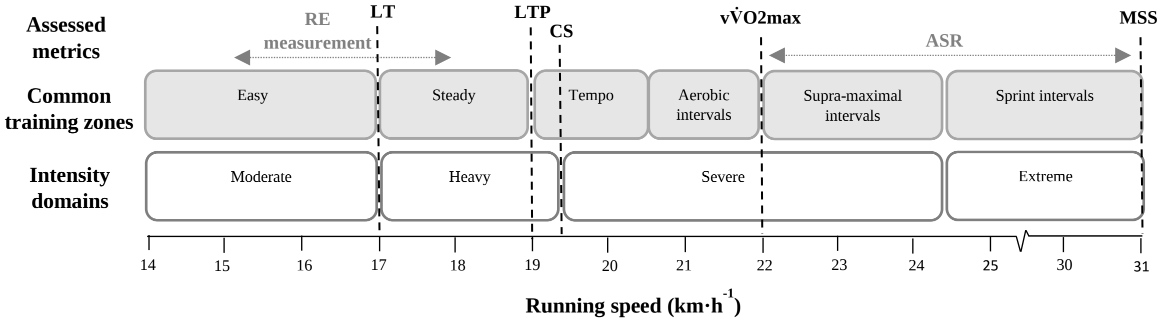

Figure 2 – A schematic example of a 1500m athlete's full physiological profile based on the testing outlined in this chapter, their relation to exercise intensity domains and commonly prescribed training zones for distance runners (Jones, 2007).

Multi-disciplinary considerations

It is important to note that if a practitioner is assessing gait spatiotemporal parameters, biomechanical differences between outdoor and treadmill running can occur. Because the exact differences found could be exclusive to a particular model of treadmill (Sinclair et al., 2013), laboratory testing should be conducted on robust, unyielding treadmills where possible. Further, as an athlete's biomechanics can affect factors such as RE (Dutto and Smith, 2002), a pre-testing period of 8 min or more of treadmill running, which can function as a warm-up, is needed for familiarisation (Arnold, Weeks and Horan, 2019).

In terms of psychological effects, social interaction has a strong effect on performance both in competition and within the laboratory; Halperin, Pyne and Martin (2015) highlighted the importance of controlling for threats to internal validity during testing, which include the number of testers, use of music, and volume and frequency of verbal encouragement. For example, the use of RPE is useful when conducting laboratory-based tests but, as a subjective measure, can be influenced by social interaction as in competition.

Competition considerations

When interpreting the results of physiological testing, it is beneficial to consider the different demands of competition, such as pacing across a championship (heats, semi-finals and finals, or multiple races), as a general strategy (e.g., negative splits in marathon) and in terms of often subtle increases and decreases in pace. For example, elite 800m runners typically cover the first 200m in a speed much faster than world record pace (Hettinga, Edwards and Hanley, 2019), which might accelerate $\dot{V}O_2$ uptake kinetics and increase the aerobic contribution to energy expenditure and sparing anaerobic capacity (Jones and Burnley, 2009). Using a treadmill makes testing easier but does not account for the changes in speed and energy cost that occur because of bend running, hills and different surfaces (Jensen, Johansen and Kärkkäinen, 1999; Mercier, Aftalion and Hanley, 2021; Minetti, Ardigò and Saibene, 1994). Indeed, although it is important that laboratory-based testing of distance runners is conducted in an internally valid and reliable manner, competitions rarely take place in such controlled conditions. Environmental chambers that allow for control of temperature, humidity or simulated altitude can assist the physiologist to test adaptations in conditions likely to occur in competition. Of course, not all external factors can be controlled (e.g., solar radiation and rainfall), but should nonetheless be considered when evaluating performance relative to testing results.

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