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Physiological monitoring of the Olympic athlete

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Abstract
As the winning margin in Olympic competition is so small, there is a continuous quest for improvements in the preparation of athletes at this standard. Therefore, even the smallest physiological improvements that result from modifications in training strategy, preparation regime or ergogenic aids are potentially useful. Unfortunately, there is a lack of research data on elite competitors, which limits our interpretation of current literature to the elite sporting environment. This places extra responsibility on the physiologist to carefully consider the most appropriate physiological variables to monitor, the best protocols to assess those variables, and the accurate interpretation of the test results. In this paper, we address the key issues of ecological validity, measurement error, and interpretation for the most commonly monitored physiological variables. Where appropriate, we also indicate areas that would benefit from further research.

Keywords: Aerobic, anaerobic, strength, flexibility, body composition

Introduction
The physiology of the Olympic athlete is characterized by extreme values at the upper limits of the physiological range, yet the measurable difference between competing elite athletes is extremely small. For this reason, measuring and monitoring changes in physiological variables in this population present extra challenges. In addition, within any preparation cycle towards an Olympic Games, changes in a single variable are unlikely to make a substantial contribution and it is often the accumulation of many changes across all the sport science disciplines that leads to successful performance. The aim of this paper is to outline the particular issues related to the physiological monitoring of an athlete preparing for Olympic competition.

Reliability and “worthwhile change”
A detailed knowledge of measurement error and reliability is vital in the assessment and monitoring of any athlete. We adopt the definition of Atkinson and Nevill (1998), where reliability is the amount of measurement error that has been deemed acceptable for the effective practical use of a measurement tool. Reliability is particularly relevant in Olympic athletes, where winning margins can be extremely small and relatively small changes in performance (<1%) result in a worthwhile enhancement of finishing position (Hopkins, Hawley, & Burke, 1999). This concept of “smallest worthwhile change” is often at conflict with traditional statistical techniques, in that trying to detect changes of <1% are virtually impossible without low measurement error and a large sample size, and thus there is a risk of type II errors. Fortunately, elite athletes are particularly reliable at reproducing both laboratory and field-based performances (Hopkins, Schabort, & Hawley, 2001), but because there is never a large sample size there is a need to ensure that the methodology employed is as error-free as possible. While it is traditional to accept a coefficient of variation below 5% (Atkinson, 2003), successful monitoring of elite athletes ideally requires lower measurement errors to determine whether any intervention is having the desired effect.

Simply believing that a particular physiological test or procedure is reliable is not acceptable; the physiologist should have assessed the measurement error for each test with the equipment to be used in the monitoring programme. Since it is recommended that such an investigation requires in excess of 40 participants (Atkinson, 2003), it is unlikely that Olympic athletes would constitute this sample, but it would be important to use as many elite athletes as
possible to ensure the results were applicable to the typical values produced by Olympic athletes.

There are a range of methods for assessing measurement error. Atkinson (2003) recommends the standard error of measurement ($\sigma_{\text{diff}}/\sqrt{2}$) or the 95% limits of agreement to determine whether there has been a real change for an individual athlete. The 95% limits of agreement is particularly conservative as it covers the full 95% of the variance, whereas the physiologist may decide it is more acceptable to choose a confidence interval that is based around 68% variance or the standard error of measurement, which covers about 52% of the error variance. Using the more conservative options leads to the risk that a meaningful change (~1%) could be rejected. Regardless, knowledge of the confidence interval of any measured variable based on the measurement error enables a valid judgement to be made on the progress within a monitoring programme. Additionally, describing measurement error in absolute values generally aids interpretation and communication to the athlete and coach.

**Aerobic fitness**

The extent to which aerobic fitness might be considered important in an Olympic event will depend upon the duration and intensity of exercise. For example, the contribution of oxidative metabolism to energy turnover in short-lasting high-intensity events such as diving or the discus throw will be negligible, and therefore the assessment of aerobic fitness in such athletes would not be worthwhile. At the other end of the continuum, oxidative metabolism will be of paramount importance in events such as the marathon, the cycle road race, and the triathlon. Between these extremes lie a number of events in which oxidative metabolism makes an important contribution to energy supply such that the aerobic fitness of the competitors might impact upon the performance outcome. These events would include all those in which all-out exercise continued for longer than about 20–30 s and those which involve a combination of high-intensity and low-intensity exercise (i.e. most team sports). It is important to remember, however, that aerobic fitness might confer other advantages to competitors even when their sport does not demand a high rate of oxidative energy supply. For example, the development of some minimal level of aerobic fitness might be important in enhancing the capacity for thermoregulation (which will be important in all sports if the Olympic Games take place in a hot and/or humid environment), in reducing resting heart rate (which might be advantageous in sports such as shooting and archery), in managing weight and body composition, and for psychological reasons.

The “parameters” of aerobic fitness include: maximal oxygen uptake ($V_{\text{O}_2\text{max}}$), exercise economy or efficiency, the kinetics of oxygen uptake in the transition from rest to exercise, and the metabolic rates that define the transitions between exercise intensity domains (i.e. the lactate threshold, and the maximal lactate steady state or critical power) (Jones & Carter, 2000). These parameters are generally well established and can be measured in an exercise physiology laboratory relatively simply and with good reliability. The nature of the sport will again dictate whether aerobic fitness can be acceptably assessed through a single “general” test of, for example, $V_{\text{O}_2\text{max}}$, or whether a more comprehensive battery of tests is necessary to encompass the aerobic demands of the sport in question.

$V_{\text{O}_2\text{max}}$

Maximal oxygen uptake represents the highest rate at which oxygen can be consumed during maximal intensity exercise, and is often considered to be the “gold standard” measurement of aerobic fitness. This is not unreasonable given that $V_{\text{O}_2\text{max}}$ reflects the integrated capacity of the pulmonary, cardiovascular, and muscular systems to transport and consume oxygen during exercise. For sports in which aerobic fitness is not a major determinant of success, the regular assessment of $V_{\text{O}_2\text{max}}$ is likely to be a sufficient indicator of changes in aerobic training status. It is generally recommended that $V_{\text{O}_2\text{max}}$ is determined using an incremental exercise test in which the athlete becomes exhausted within 8–12 min (Buchfuhrer et al., 1983), but $V_{\text{O}_2\text{max}}$ can, of course, also be established from a series of exhaustive constant-work-rate exercise tests of different durations (Day, Rossiter, Coats, Skasick, & Whipp, 2003). Interestingly, in elite endurance athletes, there is evidence that the $V_{\text{O}_2\text{max}}$ is relatively insensitive to continued training and is a poor discriminator of performance capability (Conley & Krahenbuhl, 1980; Coyle, 1995; Jones, 1998). In these athletes, $V_{\text{O}_2\text{max}}$ appears to reach high values early in the career and then to remain fairly constant even though performance continues to improve (Coyle, 2005; Jones, 2006). For this reason, it is important that such athletes complete a more comprehensive assessment of the parameters of aerobic fitness. The units in which $V_{\text{O}_2\text{max}}$ is expressed also requires consideration: in non-weight-bearing sports such as rowing, the absolute $V_{\text{O}_2\text{max}}$ (in litres · min$^{-1}$) is most appropriate, whereas in weight-bearing sports such as distance running, $V_{\text{O}_2\text{max}}$ is better expressed relative to body mass (Winter, 2007).
**Economy**

In endurance sports, in particular, the exercise economy or efficiency can be an important determinant of performance (Coyle, 1995). The term exercise “economy” is generally used in relation to running, whereas the term “efficiency” is more often applied to cycling; for practical purposes, both refer to the oxygen requirement for exercise at a certain speed or power output. A lower oxygen requirement signifies better economy. An improvement in economy as the result of an intervention such as training is important because a lower oxidative metabolic rate for a given sub-maximal speed or power output would represent a lower fraction of the VO2max and would reduce the rates of heat production and glycogen degradation. Several researchers have shown that chronic endurance training results in continued improvement in exercise economy and that this appears to be a key factor in continued performance improvements (Coyle, 1995; Jones, 1998). It is therefore essential that exercise economy be monitored in endurance athletes. In this regard, it is important to remember that economy can only be accurately assessed at those sub-maximal speeds or power outputs for which a steady-state VO2 is reached within a few minutes of the onset of exercise. Sources of possible error in the measurement of oxygen uptake can be identified and usually controlled such that exercise economy can be assessed with reasonable accuracy and reliability (James, Sandals, Wood, & Jones, 2007).

The interaction of exercise economy and VO2max determines the speed or power output corresponding to VO2max and to any given fraction of VO2max and knowledge of this speed or power at VO2max is useful in predicting performance and in prescribing training (Jones, 2007; Jones & Doust, 1998). The speed or power output attained at the end of a maximal ramp or incremental exercise test, which will be influenced by the speed/power at VO2max and also by the anaerobic capacity and neuromuscular factors, can also be useful in characterizing endurance exercise performance potential (Noakes, Myburgh, & Schall, 1990). For example, Lucia and colleagues (Lucia, Pardo, Durantez, Hoyos, & Chicharro, 1998) reported that there was no difference in VO2max between trained and elite cyclists despite major differences in maximal power output. In addition, the maximal power achieved at the end of such maximal tests is an excellent predictor of time-trial performance power (Balmer, Bird, & Davison, 2008; Balmer, Davison, & Bird, 2000).

**Blood lactate thresholds and exercise domains**

“Thresholds” linked to the accumulation of lactate in the blood have long been associated with endurance exercise performance (Farrell, Wilmore, Coyle, Billing, & Costill, 1979; Sjodin & Jacobs, 1981), and it is well known that a rightward shift in blood lactate concentration when plotted against speed or power output is both characteristic of, and highly sensitive to, enhanced aerobic fitness (Denis, Fouquet, Poty, Geyssant, & Lacour, 1982; Jones & Carter, 2000; Yoshida, Suda, & Takeuchi, 1982). Unlike VO2max, which might properly be termed a marker of aerobic power, blood lactate thresholds are sensitive indices of “sub-maximal” endurance fitness. The thresholds will, at least in part, determine the fraction of VO2max that can be sustained during endurance exercise and they might therefore be considered to reflect the aerobic capacity. Assessment of the blood lactate profile during an incremental exercise test is therefore recommended in the longitudinal physiological monitoring of those athletes for whom aerobic fitness makes an important contribution to performance (Spurway & Jones, 2007). A protocol that works well for most sports involves the athlete completing 6–9 exercise stages, each of 3–4 min duration, over a range of exercise intensities spanning 50–95% VO2max (Jones, 2007). Such a protocol enables the identification of the lactate threshold (i.e. the metabolic rate above which blood lactate concentration first rises above baseline during incremental exercise) (Farrell et al., 1979) and the lactate turn-point (the metabolic rate above which there is an inflection in blood lactate concentration and accumulation accelerates and which approximates the maximal lactate steady-state or critical power) (Kilding & Jones, 2005; Smith & Jones, 2001).

Although the association between blood lactate concentration (and even metabolic acidosis) and fatigue is tenuous (Allen, Lamb, & Westerblad, 2008), blood lactate thresholds are important in that they demarcate the various exercise domains within which pulmonary gas exchange, blood acid–base status, and muscle metabolic processes express different properties (Jones, Wilkerson, Dimenna, Fulford, & Poole, 2008; Poole, Ward, Gardner, & Whipp, 1988; Whipp & Ward, 1992; Wilkerson, Koppo, Barstow, & Jones, 2004). Sustained “moderate” exercise performed below the lactate threshold is characterized by the achievement of an early VO2 steady-state and a blood lactate concentration close to that measured at rest (i.e. 1–2 mmol·L⁻¹). In contrast, sustained “heavy” exercise performed above the lactate threshold (but below the maximal lactate steady-state/critical power) results in a delayed VO2 steady-state and blood lactate concentrations that eventually stabilize at perhaps 3–6 mmol·L⁻¹. By definition, sustained “severe” exercise above the maximal lactate steady-state does not enable the attainment of steady-states in either blood lactate concentration or VO2, the latter being
due to the emergence of the so-called “slow component”, which will ultimately drive \( \dot{V}O_2 \) to its maximum if exercise is continued (Poole et al., 1988; Whipp, 1994; Wilkerson et al., 2004). The physiological responses, and therefore presumably also the physiological adaptations to training, differ according to the domain (moderate, heavy or severe) in which exercise is performed. Regular assessment of the blood lactate profile during incremental-type exercise is therefore invaluable not only for assessing changes in training status but also in setting speed or power output ranges (or, more often, the corresponding heart rates) that will evoke different physiological responses and which can be used by coaches to optimize athlete preparation (Jones, 2007).

Although measurement of the lactate turn-point enables a working approximation of the maximal lactate steady-state/critical power (Kilding & Jones, 2005; Smith & Jones, 2001), direct measurement of the critical power (or critical speed for sports such as running and swimming) in elite athletes would be advantageous. This is because determination of the hyperbolic relationship between power output or speed and the time-to-exhaustion provides information on the curvature constant of the relationship (or \( W^* \)) that theoretically represents the total amount of (chiefly “anaerobic”) work that can be performed during exercise above the critical power (Hill, 1993). Continuous sports events requiring less than about 30 min of intense exercise are performed at intensities exceeding the critical power; the higher the power output above the critical power, the more rapidly \( W^* \) will be depleted and the sooner the athlete will become exhausted. Knowledge of the critical power and \( W^* \) can therefore be invaluable in predicting the best possible race times for a given distance and for choosing race tactics that should optimize the performance outcome (Fukuba & Whipp, 1999; Jones & Whipp, 2002). Unfortunately, direct assessment of the critical power has traditionally required a minimum of three exhaustive exercise bouts, which is rarely practicable when working with elite athletes. However, the recent development of a single “all-out” test for the estimation of the critical power (Vanhatalo, Doust, & Burnley, 2007) appears to be highly promising.

\( \dot{V}O_2 \) kinetics

The rate at which \( \dot{V}O_2 \) rises towards the “steady-state” requirement following the onset of exercise is an important, but often overlooked, determinant of exercise performance (Burnley & Jones 2007). The \( \dot{V}O_2 \) kinetics determine the magnitude of the oxygen deficit incurred in the transition from rest to exercise and thus the extent to which substrate-level phosphorylation will be accelerated and the intramuscular milieu perturbed (Jones & Poole, 2005). Faster \( \dot{V}O_2 \) kinetics, as is observed following endurance training, for example, will reduce the oxygen deficit and the extent of any fall in muscle glycogen concentration, PCr or pH, or of any increase in muscle inorganic phosphate or adenosine disphosphate concentrations, all of which have been associated with the process of muscle fatigue (Allen et al., 2008). Oxygen uptake kinetics have not been routinely measured during scientific support work with athletes, presumably due to the perceived complexity of the mathematical procedures required for accurate extraction of the pertinent parameters (cf. Koga, Shiojiri, & Kondo, 2005). However, this is likely to change in the future given the potential importance of \( \dot{V}O_2 \) kinetics to performance, especially in middle-distance events (requiring 1–15 min of exercise), and in assessing the potentially ergogenic effects of alterations in warm-up or pacing strategy (Burnley & Jones 2007).

Strength and power

Strength may be defined as the ability to generate force; the rate at which force is applied (i.e. force/velocity) is the power. Many sports require the application of high force and therefore strength; however, in most sports, it is the rate at which this force is applied (i.e. power) that is of greater importance to performance. Typically, peak power is achieved at loads of approximately 40–60% maximum voluntary contraction (MVC) (Izquierdo, Häkkinen, Gonzalez-Badillo, Ibáñez, & Gorostiaga, 2002); however, this does show some plasticity with training. Strength and power parameters are correlated with performance in several sports events; although such relationships are generally stronger in the sprint and explosive events, a significant proportion of the variance in performance is accounted for by strength and power measures in many middle-distance and endurance events.

The specific relationship between strength and endurance performance is controversial, with several poorly designed studies showing improvements in strength-based variables (Miccola, Rusko, Nummela, Paavolainen, & Hakkinen, 2007) and variables associated with endurance performance (economy, \( \dot{V}O_2 \) kinetics; Millet, Jaouen, Borrami, & Candau, 2002), but few researchers have actually measured and shown any improvements in endurance performance (Paavolainen, Häkkinen, Hamalainen, Nummela, & Rusko, 1999). There is a need for well-designed and -controlled studies with carefully matched overall training loads of highly trained athletes to correctly define this relationship. There is also a need to determine the physiological mechanism
that would contribute to any improvement in endurance performance. The relationship may depend on the nature of force production for that particular sport/event.

Factors determining strength and power include muscle cross-sectional area, muscle fibre type, the length–tension relationship, and the force–velocity relationship of muscle. Although strength and power are sometimes considered to be attributes of muscle tissue, it is important to acknowledge that the force-generating capacity is also influenced by connective tissue and most significantly the tendon. It is the composite unit of muscle and connective tissue (musculo-tendinous complex) that generates force, particularly in very dynamic movements. This is clearly seen in plyometric activities that involve a stretch–shortening cycle, in which the stretch or eccentric phase produces elastic energy and the excitation of proprioceptive organs, both of which result in increased force generation in the concentric phase of the movement (Komi, 2003).

Through specific training, the muscle characteristics that determine strength and power may be developed with consequent improvements in athletic performance. The purpose of any strength and power assessment is, in part, to quantify this development and thus demonstrate the efficacy of the training programme. Although there is evidence that strength and power adaptations may be realized at muscle lengths and velocities that are not specifically trained, the greatest gains are in the specific conditions in which the muscle has been trained (Harris, Cronin, & Keogh, 2007). It is therefore important that both strength and power training and the assessment of these attributes are performed during movement patterns that closely replicate the athlete’s event.

There are many methods by which strength and power can be assessed; these range from simple weight-lifting exercises to dynamometric assessment. Isotonic strength assessment involves the movement of constant loads; however, given the variable acceleration of the load throughout the joint range of motion, this is more accurately defined as isoinertial assessment. The performance of specific exercises with a maximum resistance (e.g. bench press, barbell squat) for a given number of repetitions (e.g. 1-RM, 10-RM) is a commonly used technique to assess strength. Tests comprising the movement of body mass (e.g. vertical jump with or without counter-movement and running tests) are also popular, and with appropriate equipment allows for the measurement of peak force, the rate of force development, and power. Isokinetic dynamometry may be used to assess isometric or isokinetic strength and power. Isometric strength assessment provides for the measurement of the maximum force-generating capacity and the rate of force development. A possible limitation, however, is that few sports require the expression of maximum isometric force; isometric strength is poorly related to sport performance and relatively insensitive to changes in dynamic strength and athletic performance (Blazevich & Cannavan, 2007). Although isokinetic assessment allows for the assessment of dynamic strength, it cannot replicate the strength–shortening cycle that is experienced in many sporting activities.

### Flexibility

Flexibility, or the range of motion about a joint or a series of joints, is improved with a specific developmental stretching programme and, for the purposes of this paper, is distinct from a pre-event stretching mobility session. The extent to which flexibility contributes to successful performance in Olympic sport varies greatly, but despite this the inclusion of stretching will be commonplace in virtually every training programme. Clearly, high degrees of flexibility or range of motion in certain joints are vital for enhanced performance in both quantitative and qualitative Olympic disciplines. Traditionally, its inclusion in training programmes is associated with the reduction of the risk of injury, yet there is a lack of well-controlled prospective studies to confirm this relationship (Witvrouw, Mahieu, Danneels, & McNair, 2004). Much of the published research originates from studies with the military, with few studies using elite athletes and there seems to be no literature that clearly demonstrates that improved flexibility enhances athletic performance. There is some evidence to suggest that hyper-flexibility may affect the stability of a joint and contribute to injury and that increased flexibility may also be related to poorer running economy (Jones, 2002). However, the recent review by Witvrouw et al. (2004) suggests that the relationship between flexibility and injury is influenced by the extent to which a particular sport utilizes near maximal stretch–shortening cycles. They suggest that in sports with low intensity or limited stretch–shortening cycles, increased flexibility may reduce performance.

There is no overall (whole-body) assessment of flexibility and measurement should be confined to single-joint complexes. Therefore, it is important that each sport carefully identifies the most appropriate level of flexibility for each joint that could contribute to enhanced performance or injury reduction. In some cases, this may simply allow the athlete to achieve a body position that is not directly related to force production or locomotion, but enables the adoption of a position that might, for example, improve control or possibly aerodynamic efficiency (i.e. cycling time-trial). There are no internationally standardized measurement techniques
for flexibility and many of the techniques are borrowed from rehabilitation medicine. However, there are three texts that offer detailed specific advice for the assessment of athletes (Harvey & Mansfield, 2000; Maud & Kerr, 2006; Phillips, 2007). It should be noted that the majority of the research and the published guidelines only address the static assessment of flexibility and thus there is a need for a better understanding of the influence of the assessment of flexibility in more dynamic situations. There is thus a need for caution, as many of the most commonly used tests of flexibility (i.e. sit-and-reach) are fundamentally flawed as accurate measures of range of motion, since they incorporate range of motion in more than one joint and thus it is not possible to extract their relative contribution to the overall measurement.

A vital starting point is the identification of suitable skeletal landmarks and it is recommended that the landmarking techniques as described by the International Society for the Advancement of Kinanthropometry (ISAK, 2006) be employed. A large range of goniometers and flexiometers exists to measure changes in range of motion, generally the choice being determined by the joint position and the type of movement involved. However, it is important that a standardized protocol of warm-up and measurement trials be established to ensure that the measurement method is adequately reliable.

If it is identified that a certain range of motion should be improved to enhance performance, there should be a development stage during which assessment should be completed on a 2–4 weekly basis followed by a maintenance phase where assessments can be less frequent.

**Anaerobic power and capacity**

High-intensity exercise requires the rapid resynthesis of ATP to provide energy for muscular contraction. The demand for ATP exceeds the rate of its supply through oxidative metabolism and, consequently, a significant proportion of the total energy demand is derived from anaerobic sources. Anaerobic power is defined as the rate at which anaerobic energy is produced; anaerobic capacity is the total amount of anaerobic energy produced. Although anaerobic power is a determinant of performance in short-duration explosive events (e.g. javelin, shot-putt, high jump), it is anaerobic capacity that is important for many sprint and middle-distance events of between 10 s and approximately 4 min (e.g. 100–1500 m running, 50–400 m swimming, 200–1000 m canoeing and kayaking, 1000–4000 m track cycling). There is a finite capacity for the anaerobic energy yield during high-intensity exercise (for reasons outlined below), which means that athletes in such events must maximize this capacity through training and exploit this energy capacity optimally during competition (i.e. effective pacing) to achieve peak performance.

Anaerobic capacity is determined by the capacities of the two anaerobic energy pathways: (1) the hydrolysis of intramuscular stores of high-energy phosphates (ATP and PCr) and (2) anaerobic glycolysis. Intramuscular stores of high-energy phosphates are small, with approximately 5 mmol and 15 mmol per kilogram of muscle for ATP and PCr, respectively. It is the magnitude of this intramuscular content that largely determines the capacity of the high-energy phosphate system. In contrast, it is not the availability of the energy substrate for anaerobic glycolysis that determines the capacity of this energy pathway, but the accumulation of various metabolic bi-products that inhibit ATP resynthesis and therefore exercise performance. Muscle fatigue during high-intensity exercise has for a long time been attributed to the accumulation of H⁺ within the cytosol consequent to the accumulation of lactic acid; however, more recent work indicates that acidosis is not the cause of fatigue in such exercise – rather, it is one of many associated symptoms (Allen et al., 2008). Other factors that may elicit fatigue and therefore determine the anaerobic capacity include the accumulation of inorganic phosphate (P₄) and potassium (K⁺) and excitation–contraction uncoupling. In repeated sprint exercise, it is the recovery of the anaerobic energy pathways (i.e. the resynthesis of PCr, the removal of metabolic bi-products, and the restoration of ionic homeostasis) that determines the extent to which exercise intensity can be maintained.

Unfortunately, there have been relatively few well-controlled scientific investigations of the physiological adaptations to high-intensity training; however, there is evidence that anaerobic power and capacity may be developed through specific training, resulting in a number of physiological adaptations, including increases in intramuscular ATP, PCr, and free creatine content, an increase in the concentration and activity of specific enzymes (e.g. creatine kinase, myokinase, PFK, phosphorylase), and an increase in the intracellular and extracellular buffering capacity (van Someren, 2006).

The measurement of anaerobic capacity is a problem that has challenged sports scientists for many years. In contrast to other physiological parameters such as aerobic power, which can be assessed by the direct measurement of oxygen consumption, there is still no one “gold standard” technique for the measurement of anaerobic capacity. There are two commonly used approaches to measuring anaerobic capacity. The first is to estimate the anaerobic energy contribution during exhaustive high-intensity exercise; techniques used include the...
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measurement of intramuscular substrate and enzyme content before and after exercise, the maximal accumulated oxygen deficit (Medbo, Mohn, Tabata, Bahr, & Sejersted, 1988), excess post-exercise oxygen consumption, and post-exercise blood lactate concentration. The second approach is to measure the work performed during a short-duration exercise test; commonly used tests include the Wingate anaerobic test, the Cunningham and Faulknner time-to-exhaustion treadmill test, and many variations of these protocols. Although such tests provide a simple quantification of mechanical work to describe the anaerobic capacity, they fail to isolate the anaerobic energy contribution. A further complication is that a significant contribution of aerobic energy metabolism to total energy turnover has been measured or estimated during short-duration exercise in a number of sports (van Someren, 2006).

Multiple-sprint tests are commonly used in the assessment of field sports players (e.g. soccer, hockey, rugby). These tests comprise a series of repeated sprints over a specified distance, separated by timed recovery periods; the recording of the fastest time and the fatigue index provide an indirect estimation of anaerobic endurance. Variations of such tests include the Bangsbo test (Bangsbo, 1994), which consists of seven repeated sprints over a 34-m course that includes a change of direction, and which are separated by 25 s active recovery.

The quantification of both an “alactic” capacity (i.e. from high-energy phosphates) and a “lactic” capacity (i.e. from anaerobic glycolysis) has been attempted via interpretation of specific substrate depletion, enzyme concentration, and work performed in both short-duration (e.g. 10 s) and longer-duration tests (e.g. \( \geq 30 \) s). The concept of alactic and lactic capacities, particularly in relation to exercise tests, is, however, confounded by the fact that the different phosphorylation pathways do not operate in isolation during exercise tests of any duration.

Body composition

The influence of body composition will depend on the nature of the sport, with weight-categorized sports and sports in which power/weight influences performance requiring a much greater degree of monitoring. In both these latter types of sports, the aim of frequent monitoring would be to achieve the required weight with minimal change in lean tissue. The physiologist should set specific targets for each athlete taking into consideration the importance for each individual sport.

There are a large range of methods available to measure and monitor body composition, all of which have varying degrees of error. Many methods depend on predictive equations. None of which were created using elite athletes. Therefore, in addition to the general reservations of this approach, the lack of specific prediction equations suggests that any method with a predictive equation should be avoided. It is recommended that surface anthropometry, as outlined by the International Society for the Advancement of Kinanthropometry (ISAK, 2006), be used to collect raw anthropometric data to monitor changes in body composition (Stewart & Eston, 2007). As the magnitude of error will depend on the skill of the assessor, measurement type and site, it is recommended that individuals undergo appropriate training to ensure an accurate measurement technique and identification of skeletal landmarks to reduce the measurement error. In addition, each physiologist should assess their own measurement error, which can then be used to make an accurate assessment as to whether a real change in body composition (beyond measurement error) has occurred.

Laboratory- or field-based testing?

An important question in structuring a physiological monitoring programme for an Olympic athlete is whether to use laboratory- or field-based testing methods. There are clearly advantages to both: laboratory-based testing enables much closer control over extraneous (mainly environmental) factors that might influence test results, thus enhancing test reliability; field-based testing occurs in the athlete’s natural sporting environment, thus increasing test validity. There is no simple answer to this question and a decision must be reached on a sport-by-sport basis. Where ergometry is available that is acceptably “sport specific”, laboratory testing can often play a key role in the monitoring programme. However, it is incumbent upon the physiologist to temper data interpretation in light of limitations to the external validity of the tests employed. A useful approach is to combine regular laboratory testing, in which test protocols are rigidly adhered to, with field-based testing, which might focus more on “problem solving”, the monitoring of training sessions, and trials of the effectiveness of interventions.

The physiological support “package”

Any physiological monitoring programme should be based on sound ethical and scientific procedures, with all parties agreeing to a realistic “contract”. An initial “needs analysis” is useful for identifying areas in which physiological support might make a measurable performance impact. The battery of physiological tests devised by the physiologist must stem from a sound understanding of the
physiological requirements of the sport, including the absolute and relative contribution of the energy pathways and the likely causes of fatigue under various conditions. All tests should be carried out for the benefit of the athlete and coach, with prime consideration given to the safety and well-being of the athlete at all times. The physiologist should be aware of the validity, reliability, and sensitivity of all the tests administered. The physiologist should also be cognisant of the limitations both of the tests themselves and of all scientific instruments used as part of those tests, and be able to identify the principal sources of error and the ways in which these might be minimized.

The frequency of testing/physiological monitoring should be agreed in advance and is likely to vary both between sports and athletes. Formal laboratory testing usefully occurs approximately every 3 months and coincides with natural changes in emphasis in the athlete’s training macrocycle. Quarterly testing allows enough time for any physiological changes resulting from a specific training intervention to become manifest, but is sufficiently frequent to assist the coach in making changes to the training programme as and if necessary.

Feedback to athlete and coach should be rapid (<48 h), user-friendly (i.e. jargon-free), and performance-focused. The feedback can be written or verbal or, most often, a combination of the two so that a dialogue can occur about the recorded data. Written reports should normally contain: an explanation of the tests performed with an indication of their purpose; a statement of the values obtained and ideally a comparison with previous values recorded by the same athlete in the same tests; and an interpretation of the values based upon factors such as the time of year and the training completed in the previous mesocycle. Indications concerning what the results might mean for performance and recommendations for training can also be valued by the athlete and coach provided that the physiologist has considerable expertise in the physiology of the sport concerned and of the training methods used in that sport. In this situation, the coach can receive valuable information about the implications of the physiological test data for the design of training sessions and the emphasis to be placed in the next phase of training.

It is vital that the physiologist is clear on his or her role in the overall scientific and medical support programme surrounding an Olympic athlete. In this way, he or she can work closely and cooperatively with professionals in other disciplines (medicine, physiotherapy, nutrition, psychology, biomechanics, strength and conditioning science) for the greater good of the athlete. Physiological monitoring is not vital for success in Olympic competition, but the fact that it is now so widespread suggests that it helps—a lot!

References


