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VIEWPOINT

Commentaries on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes – can we do better?

How to classify cyclists in applied physiology research

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TO THE EDITOR: Podlogar et al. (1) have nicely discussed current methods for classifying athletes in applied physiology studies attending to their training or performance level. We agree with them that relying on a single physiological marker such as maximum oxygen uptake is not without limitations and endorse the use of more performance-based indicators. However, before proposing critical power/speed (CP/CS) as the primary indicator of an athlete's training status, the robustness of these variables and the best method for their determination remains to be confirmed. Differences in mathematical models or test durations can indeed have a remarkable impact on an individual's CP/CS (e.g., up to ~1 km/h for CS in top-level runners) (2).

More research is needed to provide reference or "normative" values of CP/CS allowing classification of athletes into different performance/fitness categories. An alternative, at least in cycling, might be classifying athletes attending to the highest power output that they can achieve for a given duration—the so-called "mean maximum power" (MMP) (3). This approach does not require the use of mathematical calculations or additional laboratory testing and is sensitive enough to allow discerning actual performance even between the two highest category levels—Union Cycliste Internationale [UCI] ProTeam versus UCI WorldTour—in professional cyclists (4). We have recently reported normative MMP values for male (n = 144) (4) and female professional cyclists (n = 44) (5). If a similar approach was used in cyclists of a lower training/competition level, scientists and coaches could accurately classify participants in cycling physiology studies.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes – can we do better?

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TO THE EDITOR: We read with interest the Viewpoint by Podlogar et al. (1) proposing that critical power (CP, defined as power at the boundary of the heavy/severe-exercise intensity domains) rather than maximal oxygen uptake ($\dot{V}O_{2max}$) should be used as the primary descriptor of participants' training status, and we offer the following comments:

1. Correct classification of athletes should be based only on performance criteria and not on any physiological factors that, either isolated or combined, can never encompass the complexity of the multiple components of endurance performance.
2. $\dot{V}O_{2max}$ remains a gold-standard criterion and there is no doubt that values above 85 mL/kg/min characterize world-class endurance athletes. However, limiting the classification of aerobic level of athletes to $\dot{V}O_{2max}$ is restrictive and the analysis of submaximal intensity factors should complement but not replace it.
3. We disagree with the statement that CP is the best (or least bad) of these submaximal factors. Important

methodological concerns have been raised: CP is modeling-dependent (e.g., using two-parameter, three-parameter, or three-parameter exponential models) (2) or influenced by the duration of the longest trials (3). Moreover, there is a large day-to-day intraindividual variability in CP that limits its applicability for exercise prescription (4). Overall, CP may be a statistical artifact without clear physiological meaning (3). Moreover, the reliability of some CP tests is questionable (5).

To conclude, without a consensus on a valid and reliable CP determination protocol and despite the need to complement $\dot{V}O_{2max}$ with submaximal criteria, the proposal of Podlogar et al. (3) to use CP seems hazardous.

DISCLOSURES

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Classifying athlete physiology and performance—mind the environment

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TO THE EDITOR: Podlogar et al. (1) highlight important limitations with using maximal oxygen uptake alone to classify athlete physiology/performance in research studies and propose that assessing critical power/critical speed (CP/CS) would be the most appropriate method for athlete classification. Improving athlete classification in research studies is valuable but it is important to acknowledge that there can also be limitations with the CP/CS approach. For example, Podlogar et al. (1) suggest that CP/CS estimates can easily be derived from field-based testing without the use of specialized equipment. However, environmental factors such as ambient heat (2) and hypoxia (3) can influence field-based estimates of both CP and CS. In outdoor running, CS can also be potently influenced by wind velocity and terrain; failure to take these factors into account could result in misclassification of an athlete's physiology and performance capability. It is unlikely that there is a "one size fits all" approach for athlete classification. Can we do better than maximal oxygen uptake alone? Absolutely, but researchers (and peer reviewers) must also continue to carefully consider the internal and external validity of alternative athlete classification approaches.

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DISCLOSURES

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Muscle oxygenation: a relevant marker of training status

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TO THE EDITOR: Podlogar et al. (1) in their Viewpoint proposed convincingly that scientists should classify research participants based on critical power/speed derived from the power-duration relationship rather than $\dot{V}O_{2max}$. But can we do even better? It might be possible by determining critical power directly on local physiological markers. The recent study of Manchado-Gobatto et al. (2) proposed that in addition to other current systemic measurements, such as heart rate and $\dot{V}O_2$, peripheral oxygenation (including more or less active muscles) should be used to measure the internal load of training and recovery sessions. Combining the measurement of workload demands (based on accelerometer data) of exercise with its physiological responses derived from near-infrared spectroscopy (NIRS) measurement may assist in better defining a marker of training status in athletes (3). Insofar as critical power, the greatest metabolic rate achieved through the oxidative pathways, is influenced by the balance of oxygen delivery and utilization in working muscles, muscle oxygenation derived from NIRS may be used to approximate the power-duration relationship. Based on a physiological framework and empirical data, a plausible critical oxygenation was proposed with sufficient sensitivity as a counterpart of critical power method calculated at various workloads and durations (4). It is noteworthy that peripheral adaptations from NIRS-derived changes in muscle oxygenation (for upper- and lower-body muscles) have been shown to be stronger predictors of performance compared with $\dot{V}O_{2max}$ in both short and long events (5). Despite some limitations, growing technological development in NIRS equipment will favor very shortly the routine use of muscle oximetry in sports sciences.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: We appreciate the physiologically informed discussion presented in the Viewpoint by Podlogar et al. (1). However, it is well known that the determinants of endurance performance are the maximal oxygen uptake ($\dot{V}O_{2max}$), exercise economy (RE), and lactate threshold (LT) (2). The inclusion of the critical power/speed as proposed by the authors is a good alternative, although we consider that there is not enough data in the literature to compare between subjects.

$\dot{V}O_{2max}$ is strongly correlated with endurance performance in heterogeneous groups; however, this relationship is lower in homogeneous groups of endurance athletes. Thus, other factors such as fractional utilization of $\dot{V}O_{2max}$ and exercise economy/efficiency (3) might help to explain the differences between athletes. We propose to establish a classification according to the three main determinant factors mentioned above relative to the upper limit for each sport found in the literature or relative to $\dot{V}O_{2max/peak}$. For example, relative $\dot{V}O_{2max}$ values ~80 and 85 $mL \cdot kg^{-1} \cdot min^{-1}$ for female and male distance runners, respectively, have been reported previously in the literature (4). Regarding the RE, the Ethiopian runner Zersenay Tadese has showed values of 150 mL $O_2 \cdot kg \cdot ^{-1} \cdot km^{-1}$ at 19 $km \cdot h^{-1}$ or the British female distance runner Paula Radcliffe has showed values of 44 $mL \cdot kg^{-1} \cdot min^{-1}$ at 19 $km \cdot h^{-1}$. Finally, high values of LT (~83% of $\dot{V}O_{2peak}$) or lactate turn-point (~92% of $\dot{V}O_{2peak}$) have been found in elite distance runners and critical speed (CS) occurring at ~90% of $\dot{V}O_{2peak}$ (5). Therefore, a male runner with 70 $mL \cdot kg^{-1} \cdot min^{-1}$ of $\dot{V}O_{2max}$, 200 mL $O_2 \cdot kg \cdot ^{-1} \cdot km^{-1}$ at 19 $km \cdot h^{-1}$, and lactate turn-point of 80% of $\dot{V}O_{2peak}$ would represent an average 82% relative to the best distance runners.

DISCLOSURES

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Scoring tables as an alternative to classic physiological markers

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TO THE EDITOR: In their Viewpoint, Podlogar et al. (1) provided an interesting overview about the suitability of using $\dot{V}O_{2max}$ as a marker of training status in athletes. Considering that most of the literature evaluating physiological, biomechanical, and performance factors includes athletes from different events, we believe that scoring tables may be an alternative to classic physiological markers and would allow for a better comparison in such cases. In this regard, the World Athletics (former IAAF) scoring tables, which are based on exact statistical data and are updated regularly based on the latest World Records, may be helpful to identify equivalent performances of athletes specialized in different events (3). This system has been already used in the literature to classify groups of high-level runners based on the best score in their primary distance (2). Similarly, other sports such as swimming or Olympic weightlifting have their own comparable systems (FINA points, Robi points) that also allow for comparisons among different distances/styles or bodyweight categories. Therefore, in studies where participants compete in the same sport, but are specialized in different distances/styles or belong to different bodyweight categories, using specific scoring tables would be a good alternative to classic physiological variables that fail to account for such disparity of factors influencing performance.

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Could both training status and endurance performance be best predicted by a single key parameter of aerobic fitness?

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TO THE EDITOR: We appreciate the Viewpoint of Podlogar et al. (1) questioning the use of maximal oxygen uptake ($\dot{V}O_{2max}$) as a marker of training status in athletes. Basically, two arguments were used to criticize the $\dot{V}O_{2max}$: *1*) aerobic performance can be improved irrespective of an increase in $\dot{V}O_{2max}$ and *2*) $\dot{V}O_{2max}$ does not predict differences in performance in a relatively homogeneous group. In a transversal design, Greco et al. (2) found that critical power (CP, expressed as % $\dot{V}O_{2max}$) might be less sensitive than maximal lactate steady state (% $\dot{V}O_{2max}$) for depicting an enhancement in aerobic fitness. These data are not surprising, since the amplitude between CP and $\dot{V}O_{2max}$ is influenced by the curvature constant (W') of the power-time relationship (3), which is not influenced by aerobic training status (2). Thus, CP could not distinguish aerobic training status between high-trained and elite athletes. In relation to aerobic performance, Simões et al. (4) found in endurance athletes that critical speed (CS; r^2 = 0.99) was superior to predict 3,000 m running performance (performed within severe domain) than velocity at lactate minimum (r^2 = 0.83). However, 10,000 m running performance (performed within heavy domain) was better predicted by lactate minimum (r^2 = 0.98) than CS (r^2 = 0.81). Indeed, the physiological mechanisms that influence both fatigue and aerobic exercise performance are dependent on exercise intensity domain (moderate vs. heavy vs. severe) (5). Thus, there is no evidence that both status training and endurance performance can be best predicted by a single key parameter of aerobic fitness.

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Selection of suitable submaximal physiological determinants to be considered as gold standard benchmarks to determine training status in endurance athletes

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TO THE EDITOR: We agree with Podlogar et al. (1) on the need of reconsidering benchmarks of training status in endurance athletes. In our view, benchmarks should be: *1*) correlated with performance, *2*) reflective of training-induced changes in performance, *3*) easily and acceptably repeatable (e.g., submaximal effort), and *4*) amenable to goal setting. Submaximal markers such as critical speed/power model (CS/CP), and speed/power associated to second ventilatory threshold (v/pVT2), a blood lactate concentration of 4 mmol·L^{-1} (v/pOBLA), and maximum lactate of steady state (v/pMLSS), may represent better indices than $\dot{V}O_{2max}$, which is more a stable biological parameter than a reflective index of momentary training status. Speed/power associated to second lactate threshold (v/pLT2) may also be considered

(2). CS/CP can be calculated through competition performance (3); thus, factors other than physiology such as psychology and tactical skills may also define it. In contrast to measurements of v/pMLSS and v/pOBLA, those of CS/CP (3), vLT2 (2), and vVT2 (2) require near maximal/maximal effort trials, which many athletes/coaches view as time "lost from training." Alternatively, MLSS calculation requires multiple trials or laboratory visits (4). In addition, the use of blood lactate markers is sensitive to the often chronic glycogen depletion in athletes (5). Therefore, we argue that training status benchmarks in endurance athletes should be evaluated based on the four criteria presented above.

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Classification of athletes for interventional studies in sports performance research: do we really have (and need) several distinct populations?

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TO THE EDITOR: The Viewpoint by Podlogar et al. (1) stresses the need for a valid marker of training status to classify athletes participating in interventional studies. The authors start from the premise that intervention effects may differ when study participants differ from the target population and provide some examples of how studies that showed efficacy in some cohorts of athletes led to inconclusive results in higher-caliber athletes to support this point. However, this is not a solid approach to claim a lack of generalizability since several factors (bias, confounding, random error, etc.) may contribute to these "discrepancies" without necessarily meaning the existence of distinct populations (2).

Clinical research typically defines populations according to specific diagnostic criteria that inform prognosis and treatment decisions (e.g., the stages of disease). Providing an evidence-based rationale for the different cohorts of individuals should also represent the first critical step to identifying populations using continuous markers (such as maximal oxygen uptake, critical speed/power, or performance time) in sports performance research. Otherwise, regardless of the theoretical rationale for classification and marker variable choice, the risk is to create artificial cut point-based populations of limited value for the research questions we are interested in. In this regard, neither the Viewpoint by Podlogar and colleagues nor the guidelines recently proposed by other authors (3–5) fully addressed this requirement. Without solid evidence about the existence (and usefulness) of different populations across the spectrum of training status, any classification approach risks being uninformative and misleading.

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Critical speed/critical power concept: statistically appropriate fitting procedure matters

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TO THE EDITOR: As previously demonstrated by Iannetta et al. (1), a model considering intensity domains for exercise prescription and for describing physiological characteristics of individuals should be recommended. Recently, Podlogar et al. (2) suggested that the critical power (CP)/critical speed (CS), the power/speed at the boundary of the heavy- and severe-intensity domains, should be considered as the parameter that is capable of best predicting performance across a wide range of intensities.

However, CP/CS is not the only and exclusive parameter separating two intensity domains. Other parameters such as oxygen uptake kinetics, lactate and ventilatory thresholds, and maximum lactate steady state can be used. In fact, high and very high correlations were obtained between CS and ventilatory threshold, respiratory compensation point, and maximal oxygen uptake (3). Moreover, although CP/CS concept is of interest, a significant effect of the mathematical models (3) and fitting procedures (4) used to estimate CS was observed. Therefore, coaches/researchers should *1*) choose a statistically appropriate fitting procedure to their specific data set to define CS and corresponding intensity domains, and maintain it over the season (4); *2*) physiologically verify the CS estimation during the season; and *3*) use training prescription around CS (±10%) to take into account the confidence interval of its estimation and the day-to-day variability (3).

On the other hand, using CP in running could be useful to prescribe training intensity when running speed is no longer a relevant metric to rely upon (e.g., when running on a variable terrain or in a very windy condition) (5).

DISCLOSURES

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Using $\dot{V}O_{2max}$ as a marker of training status in athletes – do we have to do better?

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TO THE EDITOR: We read the interesting Viewpoint by Podlogar et al. (1), although felt compelled to comment. Agreed that vast cardiac output, oxygen uptake ($\dot{V}O_2$), and distribution are foundational for endurance performance. Assessment of lactate threshold (LT), power at LT, critical power/speed (1), and/or peak power (2, 3) provide a richer picture of athlete capacity and status. But "to see the forest rather than the trees," the issue of specificity must be addressed. The "broad brush strokes" of "athletes" itself is problematic, in that sport/event/role must be considered to even wonder if $\dot{V}O_{2max}$ is relevant. Specifically, an "endurance" sport such as cycling's penultimate Tour de France, the mountain climbers, domestiques, and sprinters all have differing tasks, which require a specific physiological profile for success. There is a reason why we know the tour winners' $\dot{V}O_{2max}$ (~80's mL/kg/min, not the 90's reported for XC-skiing), but not of sprinters, such as the notable Mark Cavendish who once retorted that he stopped a $\dot{V}O_{2max}$ test because it was "pointless" (4). As the authors highlighted (1), laboratory-based assessments of aerobic fitness ($\dot{V}O_{2max}$), while interesting, may have poor predictive validity with regard to sport performance. To quote Da Vinci, "simplicity is the ultimate form of sophistication," in that for decades before metabolic carts or lactate analyzers were widely available, let alone for coaches, routine testing of athletes in their discipline has been the coach's "yardstick." Event performance assessment is vital, as laboratory performance ≠ event performance, which reminds of an old saying in rowing . . . "Ergs don't float."

DISCLOSURES

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$\dot{V}O_{2max}$ and critical power are well correlated, but critical power is more sensitive to detect training status

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TO THE EDITOR: Regarding the interesting Viewpoint of Podlogar et al. (1), we would like to support their suggestion based on correlational data from the literature. In the 1980s, Moritani et al. (2) introduced the critical power (CP) concept to the whole body exercise, and among their results, a strong correlation between $\dot{V}O_{2max}$ and CP + W′ (r = 0.95, n = 16) was reported, suggesting that both "aerobic markers" share similar physiological mechanisms. In the following years, several studies confirmed the correlations among CP and endurance performances, lactate thresholds, and exercise (in)tolerance. In addition, Korzeniewski and Rossiter (3) demonstrated by computational simulations that $\dot{V}O_{2max}$ and CP may share similar physiological mechanisms underlying the training-induced adaptations, although we know that $\dot{V}O_{2max}$ presents a limitation for improvement, especially in highly trained individuals (1). In this regard, Mitchell et al. (4) demonstrated positive correlations between CP and different determinants of muscle oxidative capacity (i.e., the proportion of type I fibers, cross-sectional area, and capillarity) in a group of 14 endurance-trained athletes. It is noteworthy that relative $\dot{V}O_{2max}$ presented no significant correlation with any of the muscle oxidative capacity parameters. Furthermore, the coefficient of variation between subjects of $\dot{V}O_{2max}$ was 6.5%, whereas for CP it was almost three times higher (i.e., 17.2%), showing that CP detected greater group heterogeneity than $\dot{V}O_{2max}$. Finally, we support the notion that CP is a better marker of training status at least in the cycling exercise, and the CP is the actual boundary between the heavy- and severe-intensity domains (5).

DISCLOSURES

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Noninvasive skeletal muscle descriptors as future integrative alternative in training status determination

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TO THE EDITOR: We concur with Podlogar et al. (1) that determining training status solely based on maximal oxygen uptake ($\dot{V}O_{2max}$) may be too limited, particularly regarding the large diversities in physiological profiles susceptible to achieve a similar performance in a given sport. Reconsidering such "one-size-fits-all" approach with critical power/speed as the primary descriptor of training status remains similarly limited in the endurance sport spectrum (e.g., the threshold discriminating high-severe intensities is less predictive than $\dot{V}O_{2max}$ in a heterogeneous group of elite cyclists [R^2 = 0.56 vs. R^2 = 0.79; (2)]) and beyond. The complex interaction of performance determinants demands to cover the continuum of metabolic and physiological pathways (2,3) to capture more precisely a physiological profile or training status of an individual athlete.

In addition to whole body determinants, skeletal muscle descriptors offer potential to deepen our understanding of an athlete profile (3). For instance, maximal oxygen uptake of a muscle fiber is inversely related with muscle fiber cross-sectional area (FCSA) (2), although increased capillarization and higher myoglobin levels have been shown to counteract this inverse relationship (i.e., larger FCSA with higher mitochondrial oxidative capacity) (2,4). Athletes with elevated oxygen supply capacity may therefore reach better performance at similar $\dot{V}O_{2max}$ levels. In this context, noninvasive assessment of muscle oxygenation (by near-infrared spectroscopy, NIRS) may add valuable insights into the matching of oxygen supply and demand during exercise (3,5). Altogether, we advocate an integrative perspective using $\dot{V}O_{2max}$, submaximal thresholds, and noninvasive skeletal descriptors obtained from physiological profiling/testing for the determination of training status.

DISCLOSURES

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Using $\dot{V}O_{2max}$ as a marker of training status – can we do better in masters athletes too?

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TO THE EDITOR: Podlogar et al. (1) proposed that critical power/critical speed (CP/CS) rather than $\dot{V}O_{2max}$ should be used as the primary descriptor of athletes' training status. We believe that CP/CS could also be relevant to older athletes classically referred to as masters athletes. Although $\dot{V}O_{2max}$ decreases with aging in both trained and untrained individuals at a rate of 6%–10% per decade after 20–30 yr old, endurance masters athletes manage to maintain a higher $\dot{V}O_{2max}$ than age-matched inactive individuals. However, we agree that $\dot{V}O_{2max}$ alone may not be used as a predictor of performance across ages too, as we recently showed that a 59-yr-old father ran faster (2:27:52) than his 34-yr-old son (2:31:30) on the same marathon race, despite presenting a slightly lower $\dot{V}O_{2max}$ (65.4 vs. 66.9 mL·kg·min^{-1} in father and son, respectively) (2). Interestingly, some high-level masters marathoners, in addition to presenting high $\dot{V}O_{2max}$ values for their age, can sustain a very high fraction (91%–93%) of $\dot{V}O_{2max}$ up to 3 h (3,4), whereas elite young runners generally sustain 80%–85% $\dot{V}O_{2max}$ on the marathon (5). This exceptional endurance (i.e., ability to sustain a high fraction of $\dot{V}O_{2max}$ for a long duration) remains to be confirmed in intermediate-level masters athletes with a lower training volume. The interaction between the decrease in $\dot{V}O_{2max}$ and the possible increased ability to sustain high CP/CS in masters athletes requires further attention by exercise physiologists as a better understanding of this interaction could prove valuable for improving training characteristics after 40 yr of age.

DISCLOSURES

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Could we associate training status according to the performance of the top 10 athletes in the sport?

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TO THE EDITOR: We agree with the Viewpoint of Podlogar et al. (1) about the necessity of improving training status classifying methods for athletes in sports science research. The use of $\dot{V}O_{2max}$ is deeply rooted in sports; however, as well as $\dot{V}O_{2max}$, critical speed/critical power (CS/CP) may also have limitations. For example, there are some sports including more than one modality (e.g., triathlon), which would make it difficult to classify the athlete's training status only by CS/CP, considering specificity of each modality (2). Should we present CS/CP for each modality separately or present an average for all? In our view, it would be necessary to assess the sport in a full manner. Another possibility could be the use of performance of ranked athletes in the best positions in each modality and attribute classification zones for it. For instance, it would be useful to use the world top 10 competition average time in a certain modality and rank the training status from 100% to 60% of the best time, dividing by zones such as athlete, well trained, moderately trained, etc. In this way, it would take into account the factors that influence competition results, specificity, technique, or the influence of psychological and physiological factors (3). Finally, this proposal considers the performance in real conditions and it should be recognized that a simulated or laboratory test may present limited ecological validity.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: After reading the Viewpoint by Podlogar et al. (1), we would like to enrich this debate. We agree that use of $\dot{V}O_{2max}$ alone may limit and blur the classification according to the training status. For example, female athletes of the same modality with similar $\dot{V}O_{2max}$ values obtained different training status classifications (2). This discrepancy in training status classification may lead to ambiguous interpretations, compromising the practical application of the results (3). However, as previously stated (1), $\dot{V}O_{2max}$ testing approach is still one of the most used variables to report training status in scientific experiments. Indeed, in a recent literature search (nonpublished data), our group observed that between 2000 and 2020, relative $\dot{V}O_{2max}$ was the most reported variable (~61%) from the 1,003 identified studies with cyclists and runners. In addition, we found 23 and 34 training status rating variations regarding runners and cyclists, respectively. Thus, the lone use of $\dot{V}O_{2max}$ for training status classification has its flaws, while association of other metrics could be more suitable. Despite agreeing with the use of critical speed-critical power ratio, it is relevant to emphasize that this parameter also has limitations regarding the type, duration of the test, and the mathematical model used (4), with sometimes issues of over- or underestimation. Therefore, we are still far from reaching a consensus on the best metrics to classify training status. Finally, $\dot{V}O_{2max}$ could be more useful when used for clinical classification, considering a strong association between its values and mortality rates (5).

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: Podlogar et al. (1) have presented a compelling argument for using the critical intensity as an alternative method of classifying athletes. It was concluded that the critical intensity best represents the culmination of several physiological capabilities while being a strong predictor of performance. We agree that laboratory-based determination of critical intensity can be costly and time-consuming (2). However, field-based testing can be used to determine the critical intensity, which broadens the potential application of monitoring athletes in the field. Furthermore, we would like to posit that reasonable estimates of critical power (CP) and critical speed (CS) can also be derived from habitual training data. Karsten et al. (3) demonstrated that CP estimates derived from training data in cyclists showed high levels of agreement with estimates derived from laboratory testing. Smyth and Muniz-Pumares (4) showed that CS can be determined using training data in a large group of marathon runners. Importantly, these estimations were strong predictors of marathon performance. Further to training data, the use of historical best performances of elite runners demonstrates another promising avenue in which athletes may be stratified (5). Although this approach may be useful in applied conditions or athlete classification, caution should be exercised when using it for research where more accurate estimations are desirable. To summarize, the use of training data to estimate CS or CP could permit the classification of athletes. In addition, such an approach permits remote alteration of training interventions in response to changes in training status over time.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: We partially agree with the Viewpoint of Podlogar et al. (1). Regarding swimming modality, critical speed (CS) is a parameter that can predict performance in different distance trials, covering a large range of intensities (2). However, other relevant aspects are highly related with performance, such as technique, anthropometric and biomechanical factors, changing, for example, the frequency and index of stroke (2). Also, psychological factors could considerably interfere with the behavior of swimmers during competitions (3). Therefore, we believe that the use of $\dot{V}O_{2max}$ or CS alone is not enough for swimming performance level classification. Especially when analyzing swimming performance, it could be also important to consider technical efficiency, becoming more important as the distance of the events increases (4) since the strategy adopted by athletes becomes another factor that classifies performance (5). This relationship is suitable for sports that have more than one modality (e.g., triathlon), in which each sport requires specific attention. Although we have benefits with a standardized structure to characterize athletes' level, particularly in terms of research and for heterogeneous groups, the rigidity of the classification does not consider the many apparent nuances between several sports and athletes.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes – can we do better?

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TO THE EDITOR: We partly support the Viewpoint argument proposed by Podlogar et al. (1). As stated by the authors (1), there is often a discrepancy between maximal oxygen uptake ($\dot{V}O_{2max}$) and performance outcomes among athletes, which brings into question the validity (2) regarding the training status classification based on $\dot{V}O_{2max}$. We agree that training status can be better defined in the literature, whereas critical power (CP) may possess certain advantages over $\dot{V}O_{2max}$. Indeed, CP can be used to establish the lactate and ventilatory thresholds and verify $\dot{V}O_{2max}$ and can also indicate the exact power output achieved during high-intensity cycling before the crossover into the severe-intensity domain (3). This, in turn, may permit a more targeted training template compared with $\dot{V}O_{2max}$-derived training templates (3). Conversely, CP can be a burdensome test, which requires multiple laboratory visits (4). Depending on the approach, $\dot{V}O_{2max}$ testing can occur before CP testing to confirm $\dot{V}O_{2max}$ values (4). More work is needed to determine the validity as to how such measures might differentially classify training status within and between participants. Given the insufficient explanation outlined in the work, we question why the authors elected to seemingly interchange the terms "training status" and "performance," since these differ conceptually. In summary, we agree with the authors position in the use of CP in defining an optimal training status and training templates; however, consistent terminology is needed to capture fundamental differences between testing for $\dot{V}O_{2max}$ testing versus field-based performance (5).

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

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Aerobic capacity is a more important factor for training control than $\dot{V}O_{2max}$

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TO THE EDITOR: We carefully reviewed Podlogar et al.'s recent Viewpoint (1). This research agrees with the hypothesis they made on $\dot{V}O_{2max}$. For the evaluation and control of performance, factors such as critical velocity (Vcrit) and peak velocity (Vpeak) are more determinant. Hence, adopting submaximal parameters related to $\dot{V}O_{2max}$ and markers such as Vcrit, which is considered the limit between fatigue and performance during resistance exercises, has been an attraction for sports science. Long-distance runners currently complete a marathon distance at 96 ± 2% Vcrit (2). Thus, new research in this area shows a strong link between Vcrit and running endurance performance, which is crucial to the use of a variable in training prescription and monitoring (3). However, another recent determinant is the Vpeak, which considers the maximum speed reached during an incremental running test that is easy to apply and sensitive to training adaptations, as demonstrated by Manoel et al. (4), who found improvement in 10-km performance in moderately trained runners. Furthermore, the method for its determination on the track is consistent, suggesting the same for prescription, as it is closer to the reality of training and competition for runners (5). Therefore, we urge other researchers to replace $\dot{V}O_{2max}$ with simpler, scientifically validated field tests to evaluate and prescribe training in medium- and long-term endurance sports.

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: Fundamentally, we agree with Podlogar et al. (1) that the concept of critical power (CP) has considerable potential as a marker of training status. This includes its role in *1*) demarcating the boundary between the heavy- and severe-exercise domains; *2*) prescription of training sessions; and *3*) the accurate prediction of times-to-fatigue. However, the recent literature also indicates limitations of the CP concept [e.g., protocol dependency, effects of fatigue (2,3)]. In light of this, we suggest that different parameters are also taken into consideration depending on the duration of the race (4). To spare anaerobic resources, a fast increase in O_2 supply is required to keep the O_2 deficit as small as possible for shorter race durations. Regarding longer race durations, which elicit maximal oxygen consumption ($\dot{V}O_{2max}$), it seems logical that $\dot{V}O_{2max}$ best represents performance. For durations >30 min, gross efficiency along with CP most valuably represents endurance performance. Although CP is favorable to (mainly) describe the aerobic portion of endurance performance, researchers should also consider W' as an important marker for endurance performance. With sprint finishes becoming increasingly typical of race behavior, the magnitude of W' consequently has a more essential role that determines race success. However, what is not well understood to date is the effect of fatigue on endurance performance (3,5). Therefore, we encourage researchers to focus more on an athlete's ability to resist fatigue. Ultimately, we believe that a parameter that is able to accurately and reliably measure an athlete's "fatigue resistance" will best describe endurance performance.

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: We agree with the overall conclusion by Podlogar et al. (1) but would like to provide some additional considerations. Specifically, we would argue that within endurance sports, the relative importance of critical power (CP)/critical speed (CS) can differ depending on "specialization" or overall event duration, with the importance of CP/CS most likely increasing with increasing event durations. For example, the relative importance of certain maximal mean power output (MMP) durations in road cyclists can differ depending on their specialization (2). For a sprinter, the ability to perform high absolute power outputs of 10–15 s at the end of the race is of high importance for success (3). Alternatively, for a climber, the ability to perform high (relative) power outputs over long durations (>10 min) is key for success (3). Therefore, while CP will be an important performance marker for road cyclists in general, the relative importance of CP can differ depending on specialization. Although a sprinter would require a minimum CP to end up in the position to sprint for the win, a climber would directly benefit from a high (relative) CP. Reporting MMPs (or speeds) over multiple durations, or selecting ones most relevant to the athlete's event/specialization, would be of added value in addition to CP/CS when aiming to classify participants competing in different events as well as promoting valid extrapolation of the research population to sports practice. Especially considering that multiple trials, over a variety of durations, are needed to calculate CP/CS, this could be an easy-to-implement complementary approach alongside reporting CP/CS.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes – can we do better?

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TO THE EDITOR: We agree that maximal oxygen uptake ($\dot{V}O_{2max}$) is a well-established predictor of endurance performance in different populations. However, in many settings, it is not the primary determinant and may not account for all physiological regulators of exercise/performance. The authors suggest that critical power or critical speed (CP/CS), rather than $\dot{V}O_{2max}$, should be used as primary marker of training status. Although different exercise trial combinations and models have been proposed to estimate CP/CS, with shorter (higher-intensity) typically yielding higher CP/CS estimates than longer trials (lower-intensity), it is unclear if true CP/CS follows a precise hyperbolic pattern (1,2). Moreover, the ability to generate power/velocity is linked directly to the neuromechanical efficiency of agonist muscles. An increase in cadence and load are examples of intervening factors of the neuromechanical efficiency profile and affect the cost of muscle activation. These variations likely reflect the need to increase contractile frequency due to increase of co-contraction and/or mechanical disadvantages related to nonoptimal cadence (3,4). Thus, estimates of CP/CS include experimental error and biological variability. Finally, the human body consists of various interdependent systems, where multiple factors can affect exercise and sport performance. Interventions/phenomena in a specific system can trigger responses in another apparently unrelated system or generate responses and adaptations only detectable when systems are integrated (5). Although CP/CS offers more information than $\dot{V}O_{2max}$, it reflects just one relationship between physiological, mechanical, and performance aspects. It is unrealistic to assume CP/CS forms a gold standard as an isolated descriptive marker of training status among different populations.

DISCLOSURES

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Is critical power truly an improvement?

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TO THE EDITOR: Podlogar et al. (1) propose that critical power be used as the primary means for determining training status in performance-based research. A number of studies—mostly using cycling exercise—point to the efficacy of critical power in assessing training status and performance. However, what do we make of those studies, albeit few, which have found that critical power does not predict training status, or which point toward existing unknowns within the critical power framework (2–4)? Although the use of critical power has been confirmed on numerous occasions, has the requisite level of confidence been reached to transition away from using $\dot{V}O_{2max}$? Flawed though it may be, $\dot{V}O_{2max}$ offers some degree of understanding for performance levels across an assortment of exercise modalities and populations. Although various surrogate and submaximal tests exist for obtaining $\dot{V}O_{2max}$—thereby meeting the needs of a variety of athletic populations—critical power remains relatively limited in its reach for testing disparate athletic populations who use a sundry of exercise types. Though we agree with the view that critical power may be more representative of training status than $\dot{V}O_{2max}$, we wonder if existing data are substantial enough to warrant full adoption of critical power as the primary discriminatory factor of fitness. Is critical power truly "better," or are we replacing a variable that is known to be weak with a variable that is unknown to be strong? Instead of a substitute, perhaps critical power might gain in prevalence as an important supplement.

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: Podlogar et al. (1) have presented an elegant discussion on the best physiological parameters that may be used to describe the training status of athletes. Rightfully, the authors suggest that the maximal intensity at which a steady state can be achieved is a good predictor of endurance performance and offers a promising approach. Although I agree with the importance of physiological factors as a marker of training status, I believe that description of an athlete's training experience may provide additional information to distinguish elite athletes.

Indeed, two athletes of different sports backgrounds may have comparable physiological parameters. However, regardless of the level of endurance performance, sport-specific experience also brings training-related neuromuscular adaptations (2). For example, muscle coordination patterns for running exhibit considerable training-induced plasticity (3). With increasing running experience, specific patterns of muscle activation start to emerge that discriminate novice and experienced runners from elite athletes (defined based on running experience and competition results). Reshaping of muscle patterns was already noted in elite Kenyan runners (4). In addition, the presence of the specific patterns of muscle activation correlates with the progressive enhancement of the bouncing mechanism of running with experience (3), which may explain the better efficiency of elite athletes as compared with novices (5).

In essence, training induces fine-tuning of muscle patterns, only partly reflected in the physiological parameters predicting performance. Through the self-optimization process with training, the task-relevant neuromuscular adaptations of experienced athletes may result in a different response to similar intervention as compared with novices.

DISCLOSURES

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better?

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TO THE EDITOR: We agree with Podlogar et al. (1) that $\dot{V}O_{2max}$ is not enough to describe training status. Indeed, $\dot{V}O_{2max}$ is only one of the three main physiological determinants of endurance performance.

Podlogar et al. proposed critical power and critical speed (CP/CS) as an alternative marker of training status. However, CP/CS is a performance measure, not a physiological marker. In fact, mental fatigue influences the outcomes of these assessments (2).

In our opinion, the following four parameters are better than both $\dot{V}O_{2max}$ and CP/CS as markers of training status relevant to different endurance athletes. Furthermore, they can all be measured during a standard incremental test: *1*) power output/velocity (PO–V) at maximal fat oxidation as a marker for athletes involved in ultra-endurance competitions (3); *2*) PO–V at threshold (i.e., lactate threshold, respiratory compensation point, 15 on the Borg's RPE scale), for competitions from 1 to 3 h (4); *3*) the minimum PO–V that elicits $\dot{V}O_{2max}$ for competitions ranging from 3 to 20 min (5); and *4*) peak power output/peak running velocity, an additional performance-based parameter to further distinguish training status (4).

Alternatively, when testing is not feasible, training and competition history (e.g., training volume per week, personal best time in a 5-km race) provide a very good classification of training status, such as the framework mentioned in the Viewpoint.

DISCLOSURES

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Using $\dot{V}O_{2max}$ as a marker of training status in athletes - can we do better for athletes with spinal cord injuries?

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TO THE EDITOR: The authors eloquently described the limitations of using maximal oxygen uptake ($\dot{V}O_{2max}$) as the gold standard for predicting endurance performance among nondisabled athletes (1). For Paralympic athletes with spinal cord injuries (SCI), the differences between $\dot{V}O_{2max}$ and endurance performance can be significantly affected by the level and severity of the SCI, thermoregulation, and other factors affecting the autonomic nervous system. By solely considering the Fick equation during either incremental or continuous high-intensity exercise tests (2), it is evident that athletes with paralysis due to SCI will have lower values because of the central and peripheral impaired cardiovasculature. Autonomic impairments related to SCI will decrease venous return, stroke volume, cardiac output, and lower heart rate during exercise (3). Furthermore, decreases in metabolically active tissue and oxidative capacity (4) significantly affect oxygen uptake. Baumgart et al. (5) conducted a systematic literature review, meta- and pooled-data analysis to identify $\dot{V}O_{2peak}$ values in Paralympic sitting sports, examining between-sports differences and within-sports variations in $\dot{V}O_{2peak}$ and determining the influence of sex, age, body mass, disability, and test-mode on $\dot{V}O_{2peak}$. Fifty-six percent of the participants included had SCI. They found significant variability in $\dot{V}O_{2peak}$ values ranging from 45.6 mL·kg^{-1}·min^{-1} for Nordic skiing athletes to 18.9 mL·kg^{-1}·min^{-1} for rugby players. Therefore, $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ values need to be interpreted carefully in sports disciplines with few included studies and considerable within-sports variations. Furthermore, the development of measurements and protocols to predict endurance performance in this population is critical for the periodization of training and also for equity and inclusivity.

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Commentary on Viewpoint: Using $\dot{V}O_{2max}$ as a marker of training status in athletes – can we do better?

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TO THE EDITOR: We concur that sports science-related studies should correctly classify their participants so that no inaccuracies may happen when transferring the obtained findings to the training routines (1). However, we disagree that $\dot{V}O_{2max}$ is often used for participants classification as it is difficult to assess it in real-practice conditions and there are punctuation scales based on competition performances employed for standardizing research results (like the International Swimming Federation points) (2). Subjects' $\dot{V}O_{2max}$ is frequently used for defining their training status but mainly on studies conducted in controlled laboratory settings (e.g., using treadmill and cycle/rowing ergometers). The eventual mismatch between performance level and classification based on participants' $\dot{V}O_{2max}$ might be due to their specialization (e.g., short, medium vs. long-distance events and individual vs. team sports), the different assessment methodologies (3), and the $\dot{V}O_{2max}$/$\dot{V}O_{2peak}$ issue (4). We also agree that having the highest $\dot{V}O_{2max}$ is no guarantee of success (1), since the time to exhaustion at the velocity $\dot{V}O_{2max}$ is typically 5–10 min (5), much shorter than the duration of long-distance cycling, running marathons, and open water swimming events. However, is the CP/CS a satisfactory alternative or just another important indicator for athletes exercise monitoring? Since it represents a different intensity domain ($\dot{V}O_{2max}$ is the gold standard for severe exertions), it would well characterize some efforts but not directly associate with performances at lower and higher intensities. Moreover, we wonder if CP/CS assessment would be feasible and practical in everyday settings, i.e., in the conditions in which training and competition occur.

DISCLOSURES

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A further benefit of using critical power/speed to determine participant status

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TO THE EDITOR: Podlogar et al. (1) propose that sports scientists use critical power/speed (CP/CS) tests to classify research participants' performance. Indeed, that is what we did in an ultramarathon running study (2), in which participants initially completed a field-based CS test. Opportunely, this commentary gives us the chance to present our views. As highlighted in the Viewpoint (1), some CP/CS testing protocols are fairly practical and may provide performance insights over a decent range of exercise durations. Field-based CP/CS tests have the additional benefit of a high ecological validity (3), unlike laboratory-based incremental tests used to determine maximal oxygen uptake. Most important, however, is that field-based CP/CS tests require little specialized equipment, particularly for running. This benefit is relevant to multiple laboratories across the world that might lack gold-standard treadmills, ergometers, or gas analyzers. We argue that CP/CS tests represent an elegant, cheap (or the cheapest), and effective method to democratize the scientific approach to performance classification, allowing staff and students of low-income institutions/countries to conduct research even when expensive equipment is not readily available—as in our case (2). Ultimately, the proposed approach for performance classification of research samples might contribute, at least partially, to promote a level playing field when it comes to research output potential and ability to attract grants, a necessity already acknowledged in other fields (4). It is, nevertheless, important that sports scientists agree on a set of methodological guidelines for the implementation of field-based CP/CS tests before these become the norm.

DISCLOSURES

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Maximizing data from a $\dot{V}O_{2max}$ test to enhance participant classification in research studies

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TO THE EDITOR: We concur with Podlogar et al. (1) that participant classification in research studies can be better defined. Beyond maximal oxygen uptake ($\dot{V}O_{2max}$), there are other important determinants of endurance performance including lactate threshold and exercise economy/efficiency (2). Measuring critical power/critical speed (CP/CS) holds value for the points raised by the authors (1). A potential limitation of the method for directly determining CP/CS is participant burden as it typically involves several exhaustive exercise tests over multiple days (3). We encourage researchers to also consider maximizing the information that can be gleaned from a traditional $\dot{V}O_{2max}$ test. In addition to peak power at $\dot{V}O_{2max}$, submaximal variables can be derived that are useful for classifying performance ability. These include ventilatory threshold one (VT1), respiratory compensation point (RCP), and various measures of exercise economy/efficiency. VT1 can serve as a noninvasive proxy of lactate threshold and help inform exercise prescription because it differentiates the moderate- and heavy-intensity exercise domains (4). RCP reflects the second breakpoint in the ventilation-power relationship during an incremental test. Meta-analysis has shown that the RCP and critical power (CP) are positively correlated (r = 0.80) although the former overestimated the latter by ∼6% and thus is not a direct index (4). Finally, gross/delta efficiency and economy can be calculated as energy required per work produced (5). Traditional $\dot{V}O_{2max}$ testing can thus provide parameters beyond "maximal" values that can be useful for classifying training status and performance ability. This is not to diminish the value of alternative tests including CP/CS measurements.

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$\dot{V}o_{2max}$ and other factors in the classification of athletes

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TO THE EDITOR: The investigations of Hill and Lupton showed that above a certain intensity of exercise there is no corresponding increase in the uptake of oxygen, $\dot{V}O_{2max}$, despite increase in the intensity of exercise. Measuring $\dot{V}O_{2max}$ proved vital as it helps in assessing the pulmonary-cardiovascular-metabolic systems, transport and utilization of O_2 to support muscle contractions, and the efficacy of interventions designed to enhance cardiopulmonary fitness (1). On the other hand, critical power (CP) is a threshold of oxidative metabolism or a "fatigue threshold" below which athletes can perform indefinitely and is the horizontal asymptote of power-duration curve. Above that, anaerobic metabolism predominates, and accumulation of metabolites such as ADP, P_i, K^+ set in fatigue (2). $\dot{V}O_{2max}$ has been used to classify athletes as elite or not; but recent reports (3) point to mismatch between $\dot{V}O_{2max}$ and performance levels in professional athletes. The authors of the Viewpoint (4) question the uniqueness of $\dot{V}O_{2max}$ in validating the classification of athletes given this disparity in $\dot{V}O_{2max}$ and performance and point to CP/CS as the most appropriate way to do this. In addition, in current methods of testing $\dot{V}O_{2max}$ in different populations, there are some inconsistencies reported, as noted by McNulty and Roberg, namely, mode of testing protocol duration, protocol type, health and fitness status of the subject, subject motivation, familiarity with the mode and workloads, etc. (5). Other parameters such as blood lactate threshold and exercise efficiency have a definite bearing on CP. Nonbiochemical factors like training history, exercise equipment, and psychological make-up, may impact the CP.

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