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Commentary on Seiler's *History of Endurance Testing in Athletes*

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Sportscience 15, 93-94, 2011 (sportsci.org/2011/wghmb.htm)

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We were somewhat surprised by the intensity of Frank Katch's criticism of Stephen Seiler's *History*. Seiler defined the scope of his presentation as the history of the current endurance performance model: performance power = VO_2max x (fractional utilization) x (work efficiency) + (anaerobic capacity). Katch has done an admirable job of complementing Seiler's history of this model with the earlier history of endurance assessment. Seiler appears to have done justice to the more recent history of assessment of oxygen uptake, although the recent history of athletic performance testing in general still needs to be written.

Katch also claims at the end of his critique that the proper assessment of endurance performance "requires a new set of parameters waiting to be discovered". Again, the theoretical basis of the model and the practical application to athletes is also somewhat outside the scope of Seiler's presentation. Indeed, Seiler made the following comment to us during the review process: "I am trying to publish something that has some utility as a teaching tool. In that regard, I think it is great if it can be used as a starting point for discussions of all these issues in the teaching setting." With that comment in mind, we would like to support Katch's claim. There is a sense in which the model described by Seiler has to be 100% formally correct: for exercise at constant pace to exhaustion below VO_2max intensity, when multiplied together the three VO_2 variables in the model *have* to predict endurance power output exactly (without any anaerobic term). In practice they don't, for two reasons. First, all three variables require measurement of VO_2, and VO_2 has noise that is seldom as low as 1-2% and often much worse. When you multiply all three variables together, the noise compounds to around 3% or more, and when you consider that the smallest important change in endurance power output for a top athlete is ~0.3-1.0% (depending on the sport: Hopkins, 2004), it's clear the model isn't going to be particularly useful. Noise in the variables and the fact that they all contribute to endurance performance explains why individually they can have the low correlations with performance that Katch referred to. The second reason why the model doesn't work well is that fractional utilization is seldom if ever measured directly as mean VO_2 in the exercise divided by VO_2max: that measurement would require the athlete to breath into respiratory apparatus throughout the exercise, and it's not something athletes or researchers want to do. Instead, the surrogate measures of lactate or ventilatory threshold are used. Although these measures have the added bonus that they can be measured along with economy and VO_2max in a single incremental test, as surrogates they introduce more error, not only because they aren't exactly the same as fractional utilization, but also because they are probably more noisy than fractional utilization.

So much for exercise below VO_2max, but what about endurance above VO_2max? The current submaximal model can be applied to such exercise in theory by setting the fractional utilization to 100%. You also have to assume that economy remains the same as when measured submaximally, because you can't measure it properly at or above VO_2max. Anaerobic capacity now enters the model, but the anaerobic capacity needs to be divided by the duration of the exercise so that power outputs from anaerobic and aerobic sources add up to the power demand of the exercise. What we have now is the familiar critical-power model, which is itself limited in its theoretical basis and practical application: sweeping assumptions are required (summarized in Hinckson and Hopkins, 2005), and we know of no-one applying it in practice with athlete assessment. Furthermore, the critical-power model does not make sense at or below VO_2max, even though misguided researchers have sometimes applied it to such intensities.

So we agree with Katch that researchers need a new model, especially one that works well for intensities around VO_2max. The model needs parameters that we can measure easily and accurately and that we can train selectively. If, as seems likely, one or more of the parameters is related to an intramuscular metabolite that builds up or decays to some critical value (and is therefore responsible for fatigue), use of the model with top athletes won't be practical until a new technology allows the metabolite to be measured without biopsies. Until then, empirical models of the way an endurance athlete's performance changes with exercise intensity (e.g., Hinckson and Hopkins, 2005) are probably more useful than models that depend on measurement of VO_2.

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Published Nov 2011