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A Brief History of Endurance Testing in Athletes

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Modern laboratory testing of endurance athletes has evolved over six decades, beginning with the establishment of maximal oxygen consumption (VO2max) as a valid and repeatable measure of aerobic capacity. While A.V. Hill introduced the concept of VO2max already in the 1920s, it was Henry Taylor, Per-Olof Åstrand and Bengt Saltin in the 1950s and 60s who performed seminal methodological studies that established appropriate protocols and physiological indicators for its measurement. Normative data from Åstrand and Saltin published in the 60s for a range of sports showed a clear relationship between high-level endurance performance and high VO2max. Research on energy metabolism as a function of workload began properly with August Krogh, who built an accurate cycle ergometer by 1910. Margaria, Dill and Edwards published a curve of the oxygen debt-workload relationship that looked much like a blood-lactate profile already in 1933. Wildor Hollman, from the German University of Sport in Cologne, was almost certainly the first to display ventilatory and blood-lactate responses as a function of intensity and to identify a breakpoint, presenting his findings at an American congress in 1959. Unfortunately he did not publish in English, so all credit for the concept went to Karlman Wasserman. In his classic 1964 paper, Wasserman coined the term *anaerobic threshold* to describe changes in the respiratory exchange ratio as a function of workload. Wasserman later teamed with William Beaver to develop technology for breath-by-breath measurements that facilitated the ventilatory breakpoint approach to threshold testing. Meanwhile Hollman and other Germans from Cologne (Heck, Mader, Stegman, Kindermann, and Beneke) were highly influential in developing lactate-threshold methodology, analysis and terminology. Our understanding of lactate metabolism in terms of production and elimination has resulted in deemphasis of the term *anæerobic*, but the methods of threshold testing have changed minimally in the last three decades. Finally, the importance of work economy or efficiency as a partial predictor of endurance performance emerged in 1973, when David Costill demonstrated that oxygen cost for a given running speed varied by ~15% among well-trained runners. Costill was one of the earliest investigators to integrate the trio of VO2max, fractional utilization, and work economy as the testing model that has spread throughout the world since its validation in numerous laboratories in the 1980s. KEY WORDS: efficiency, lactate threshold, maximal oxygen consumption, work economy.

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Reviewers' Commentaries: Katch · Hopkins and Buchheit

Hundreds of laboratories around the world perform physiological testing on endurance athletes as part of ongoing assessment or research projects. Three core variables are routinely measured: the maximal oxygen consumption, the lactate threshold, and work economy or efficiency. In 2010, I gave a lecture to the Norwegian sports medicine congress in which I traced the development of this triad through the key investigators and seminal papers that influenced their acceptance. This article contains the slideshow I presented in that lecture.

History lectures are dangerous: one is forced to compromise completeness for the sake of flow and focus. My organizing theme was the current physiological performance model for endurance and the laboratory-based testing of endurance athletes. I also focused on classical studies that emerged through evaluation of citations. I had to filter out a large amount of interesting history related to field tests, fitness testing, cardiovascular risk assessment and so on. Note also that, while I focused on the "standard endurance testing model", this lecture is not an endorsement of all aspects of that testing regime and it does not explore in depth the research that supported or questioned the underlying mechanistic paradigm. So, accepting those caveats, I hope the material is useful to students of exercise physiology who sometimes have no time to think about the big sweep of historical developments in their field as they race to add new pieces to their physiological jigsaw. Key references are included in the slideshow.

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