The following is the abstract of the article discussed in the subsequent letter:

**Coyle EF.** Improved muscular efficiency displayed as Tour de France champion matures. *J Appl Physiol* 98: 2191–2196, 2005. First published March 17, 2005; doi:10.1152/japplphysiol.00507.2005.— This case describes the physiological maturation from ages 21 to 28 yr. Maximal oxygen uptake (VO₂ max) in the trained state remained at ~6 l/min, lean body weight remained at ~70 kg, and maximal heart rate declined from 207 to 200 beats/min. Blood lactate threshold was typical of competitive cyclists in that it occurred at 76–85% VO₂ max, yet maximal blood lactate concentration was remarkably low in the trained state. It appears that an 8% improvement in muscular efficiency and thus power production when cycling at a given oxygen uptake (VO₂) is the characteristic that improved most as this athlete matured from ages 21 to 28 yr. It is noteworthy that at age 25 yr, this champion developed advanced cancer, requiring surgeries and chemotherapy. During the months leading up to his Tour de France victories, he reduced body weight and body fat by 4–7 kg (i.e., ~7%). Therefore, over the 7-yr period, an improvement in muscular efficiency and reduced body fat contributed equally to a remarkable 18% improvement in his steady-state power per kilogram body weight when cycling at a given VO₂ (e.g., 5 l/min). It is hypothesized that the improved muscular efficiency probably reflects changes in muscle myosin type stimulated from years of training intensely for 3–6 h on most days.

**Has Armstrong’s cycle efficiency improved?**

To the Editor: The concept that extensive endurance training improves cycling efficiency is intuitively appealing but not well supported by the literature. Recently, Coyle (1) has published efficiency data from Tour de France Champion, Lance Armstrong. In this case study Coyle concluded that “the physiological factor most relevant to performance improvement as he matured over the 7-yr period from ages 21 to 28 yr was an 8% improvement in muscular efficiency when cycling” (1). Case studies documenting adaptations in truly elite endurance athletes are important (3); however, we believe Coyle’s case study is insufficient to support his conclusions because of limitations in study design and methodology.

**Timing of testing sessions.** Armstrong was tested five times over a period of 7 yr. Only the first and last test occurred during the same month (November), making it difficult to distinguish seasonal effects from maturation effects. Unfortunately, Armstrong’s fitness data within 3 mo of racing a Tour de France tour is not reported. The majority of the improvement in gross cycling efficiency (GE) occurred after January 1993 (21.6%) and before August 1997 (22.7%), 8 mo after cancer treatment. Consequently, if there were real changes in GE it becomes difficult to distinguish whether the improvements in GE are due to cancer treatment or important aspects of training (e.g., training load, altitude training, high-cadence training, time-trial training, or resistance training).

**Accuracy and reliability of efficiency.** Coyle does not present data documenting the accuracy and reliability of the techniques used to calculate cycling efficiency (oxygen uptake, carbon dioxide production, and power output). Friction-braked bicycle ergometers have been shown to be inaccurate when dynamically calibrated (4). Previous research has reported that Monark ergometers tend to underestimate power output by ~2–8% (4). If Coyle’s Monark ergometer was inaccurate, then Armstrong’s actual GE before winning his first Tour de France may have been ~19–21%, values similar to those reported for recreational cyclists (5). Also of concern is the observation that the accuracy of Monark ergometers can change with age (4). Without routine assessment of accuracy with a dynamic calibration rig, it is difficult to know whether the Monark used in Coyle’s study changed over the 7-yr period of data collection.

**Were all tests performed on same ergometer?** The terminology used by Coyle to describe the “same Monark ergometer (model 819) used for all cycle testing” is confusing. In the METHODS section, Coyle states that “the calibrated ergometer was set in the constant power mode” and in the DISCUSSION section that there was “a progressive loss of pedal cadence at constant power during the 30–60 s before exhaustion.” Although we are unaware of a constant power mode for Monark (model 819) ergometers, this mode of operation is commonly used with a Lode electromagnetic ergometer. A Lode ergometer has been used in Coyle’s laboratory (2). It is possible that either inappropriate terminology was used in the METHODS section or Armstrong was tested on two different types of ergometers.

**Is efficiency responsible for success?** Without the appropriate data, Coyle is left to speculate that, during the Tour de France tours (1999–2004), Lance possessed a maximal oxygen uptake (VO₂ max) of ~6.1 l/min (based on the September 1993 testing session) and a body mass of ~72 kg (based on “his reported body weight”) and therefore a relative VO₂ max of 85 ml·kg⁻¹·min⁻¹. These estimations suggest that efficiency improved (21.2–23.1%; ~9%), while VO₂ max rose (70–85 ml·kg⁻¹·min⁻¹; ~21% increase) and body mass fell (from 78.9 to 72.0 kg; ~9% decrease). In contrast to Coyle’s conclusions, it appears that conventional physiological adaptations to modifications in diet (loss in body mass) and training (gains in aerobic power) may be equally, if not more, important to Armstrong’s performance than the 9% improvements in cycling efficiency.

In summary, although great insight into human physiology can be gained from carefully controlled examinations of elite athletes, poor experimental design and methodology can lead to inappropriate conclusions, which in the case of a sporting hero can quickly become more hype than fact. Coyle’s data supporting the assumption that training can improve cycling efficiency in an elite cyclist are not compelling. It appears that other more conventional explanations describing why Armstrong is such a successful cyclist may be equally tenable.

**REFERENCES**

It should be noted that our references to “a specially designed ergometer” (3, 7) include continuous and integrated measurement of the Monark pendulum displacement force using a potentiometer with a reliable measurement accuracy of ±0.4 N. Furthermore, cycling cadence was measured (±0.18 rpm) continuously throughout each pedal revolution (3, 7).

3) Point 3: Were all test performed on the same ergometer? All the data presented on Armstrong in this manuscript (4) were indeed collected from the “same” ergometer (i.e., only one unit used). Monark did indeed manufacture an ergometer (819) in the 1980s that possessed electronics that integrated cadence and force in order to hold power constant. I hope this addresses the suspicions. For what it is worth, the electronic circuitry of our 819 ergometer became nonrepairable as did our system for measuring indirect calorimetry. However, Armstrong is still going strong, albeit with a few repairs.

4) Point 4: Is efficiency responsible for success? Improved mechanical efficiency and power (watts) accounted for approximately one-half of Armstrong’s improvement (i.e., 8–9%), and an 8–9% reduction of body weight (kilograms) accounted for the other one-half (4). Thus watts per kilogram increased by 18%. Speculation about maximal $\dot{V}O_2$ ($V_{O2max}$) during the Tour de France is not needed to calculate watts per kilogram. The notion that endurance performance is related only to $V_{O2max}$ was conventional long ago (5), and Martin et al. might find enlightenment by considering models that also integrate submaximal muscle stress (e.g., lactate threshold) and performance power or velocity (1, 2).

REFERENCES


Edward F. Coyle
Department of Kinesiology and Health Education
The University of Texas at Austin
Austin, Texas 78712
e-mail: coyle@mail.utexas.edu