Letters To The Editor

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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* 99: 2191–2196, 2005. First published March 17, 2005; doi:10.1152/japplphysiol.00563.2005.—This case describes the physiological maturation from ages 21 to 28 yr of the bicyclist who has now become the six-time consecutive Grand Champion of the Tour de France, at ages 27–32 yr. Maximal oxygen uptake ($\dot{V}O_{2\,max}$) 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% $\dot{V}O_{2\,max}$, 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 ($\dot{V}O_2$) 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 each of 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 $\dot{V}O_2$ (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.

Scientific considerations for physiological evaluations of elite athletes

To the Editor: Elite athletes are valuable study objects for exercise physiology: successful sportsmen offer unique insight into the extreme adaptation of the human organism to certain types of exercise and illustrate the amazing adaptation capacity of human physiology (9). Because of the unique characteristics of the study subjects, sample sizes in these investigations are usually low. Even case reports, such as in the article written by Dr. Coyle (1), can therefore be a valuable contribution to the scientific knowledge in this field.

Nevertheless, such studies should respect the basic principles of scientific investigations. We feel that the investigation presented by Dr. Coyle has serious limitations in this context.

Experimental design. The aim of the study was, according to the author, to report "the physiological changes that occur in an individual bicycle racer during a 7-yr period" and thereby illustrate "the extreme to which the human can adapt to endurance training." Unfortunately, the data presented in the manuscript do not contain enough physiological information of the athlete in question (Lance Armstrong) to draw a picture sufficient to illustrate his physiological profile and the associated adaptations over 7 yr: in fact, no testing was performed in immediate connection with his Tour de France wins. It can be assumed that his physiological performance at that moment was much higher than the ones measured and described by the manuscript. The performance data reported in the manuscript are common to many elite cyclists (4, 5), none of whom matches the wins of Armstrong. Furthermore, the exercise tests outside the cancer period date from the months of January, November, and September; these are periods where professional cyclists, who target peak form for races in July, have barely the same condition as during their peak season. Therefore, all speculations in the manuscript on potential data during his Tour de France wins are not supported by any of the presented test results. To display a complete physiological profile of the athlete and to draw the present conclusions, at least some data from peak season testing should have been included. Interestingly, no data from the years of best performance of the athlete are presented: during the period from 2000–2005, Armstrong won five consecutive Tours de France; unfortunately, no exercise test seems to have been conducted during that time, which is rather surprising for an athlete of Armstrong's caliber.

Methods. To evaluate exercise performance and draw valid conclusions, it is essential to report data on the reliability and accuracy of the testing equipment, especially when only small changes are expected or the accuracy of the testing equipment is poor. In exercise physiology, especially the assessment of respiratory data is prone to errors linked to the testing procedure. This error, together with biological variation of maximal oxygen uptake, has been demonstrated to reach up to 5% (3, 8), thereby almost equaling the changes described in the manuscript. The same applies to the ergometry equipment: it has been demonstrated that many ergometers yield a high inaccuracy in their measurements, especially mechanically braked models, such as the one used for the present investigation (6, 10). In a comparable case report which uses the same type of mechanically braked ergometer (9), the authors included a 9% correction for their power measurements.

Unfortunately, the author does not report any data on the accuracy and reliability (such as calibration data) of his testing equipment. Especially when evaluating the calculations and conclusions drawn from the data, this would be of great help.

Furthermore, we are not aware of a reliable constant power mode in mechanically braked ergometers, such as the Monark model used for several tests in the present study.

Results and discussion. The author highlights the importance of improved muscular efficiency as being the main reason for Armstrong's outstanding gain in performance. We feel that this assumption cannot be made on the basis of the presented information, because no records are available from periods where the athlete actually had peak form. In this context, Fig. 1 is not correct, because it implies that Armstrong's gross and delta efficiency have been constantly rising since the age of 20 yr, despite a period of more than reduced physical condition during cancer treatment. On the basis of the presented data, the author cannot judge the efficiency of any other moment than the ones studied (November 1992, January 1993, August 1997, November 1999). Furthermore, the conclusion of the manuscript is even more surprising, because it has been shown that efficiency is not a key factor to differentiate between successful and unsuccessful cyclists (2, 7). Unpublished data from our laboratory support these assumptions: elite cyclists do not show higher efficiency than recreational cyclists. Furthermore, a high interindividual variability can be noted. In a longitudinal follow-up (intraindividually), however, efficiency remains remarkably stable, even when overall physiological exercise performance highly varies.

It is therefore more likely that, in addition to very favorable genetic assets of the athlete, common physiological adaptations associated with endurance training, such as an improved aerobic and possibly anaerobic energy metabolism, increased power-to-weight ratio, or enhanced recovery functions, might have added to the truly outstanding sporting achievements of Lance Armstrong.

It has to be considered that, aside from being determined by purely physiological factors, performance in sporting competitions is highly influenced by many other variables, such as tactical race understanding and motivational and psychological issues. Although speculative, the latter two might play a prominent role in Armstrong's sporting achievements, especially when considering the athlete's unique medical history and human experience as a cancer survivor. Armstrong might have gained the edge over his physiologically equally strong competitors by these means.

We feel obliged to raise these issues to the scientific community on behalf of all scientists working with elite athletes. Even when the popularity of an athlete might strongly influence the interest of publishing data, both from the author working with the athlete and the editor's side, the basic principles for scientific investigations should be respected. Published data (especially if published in a highly regarded scientific journal like the *Journal of Applied Physiology*) represent the base of knowledge and interpretation for future investigations and should therefore fulfill these scientific principles to allow upcoming studies to rely on the validity of their outcomes.

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Yorck Olaf Schumacher
Stefan Vogt
Kai Roecker
Andreas Schmid
Department of Sportmedizin
Medizinische Universitaetsklinik Freiburg
79106 Freiburg, Germany
e-mail: olaf@msm1.ukl.uni-freiburg.de

REPLY

To the Editor: I thank Dr. Schumacher et al. for the opportunity to discuss the reliability and validity of our methods. Regarding "scientific considerations," this study focused on physiology and not the science of bicycle racing. Our main purpose was not to make measurements around the Tour de France or to compare this subject (Lance Armstrong) with other champions. The fact that our subject happened to eventually win the Tour de France was interesting but not the main "scientific consideration." Changes in muscle efficiency with 7 yr of training was the focus.

Reliability was most important, both in terms of the subject as well as the measurements of indirect calorimetry and power. This subject's level of training and accessibility were most reliable from year to year in the early part of the competitive season when most of our measures were made. Besides, our study of Armstrong began before he ever competed in the Tour de France. The fact that we did not report data after this subject won his first Tour de France emphasizes, again, that our purpose was to observe the maturation and not report the characteristics of the existing champion.

Schumacher et al. have requested data regarding the reliability of our respiratory testing equipment for measuring oxygen consumption. During submaximal exercise at 60–70% maximal oxygen consumption in a group of competitive cyclists (circa 1994), we have observed that oxygen consumption when measured on 8 separate days in a given individual displayed an average range of 0.08 l/min and a coefficient of variation of ±0.87% (2). See Martin et al. (5) for additional insight. The notion that a set 9% correction should be applied to all Monark ergometers is not supported by Maxwell et al. (6). The model 819 Monark ergometer used by Armstrong was calibrated statically and dynamically using pedal dynamometers and found valid to within ±3% (1, 4), and power can be held constant [as detailed in Martin et al. (5)].

Schumacher et al. state that "Fig. 1 is not correct" and then say that "on the basis of presented data, the author cannot judge the efficiency of any other moment than the ones studied (November 1992, January 1993, August 1997, November 1999)." The manuscript never "judged" or speculated about efficiency as it only reported actual data. Removing data from 1997 does not alter the line between 1992 and 1999. These data over years, to our knowledge, are the only published addressing long-term efficiency and training. These data seem to conflict with notions of Schumacher et al., because they state "efficiency is not a key factor to differentiate between successful and unsuccessful cyclists" on the basis of their own unpublished data as well as the work of others (7). We have presented a model of how numerous physiological factors interact to determine endurance performance and have discussed that efficiency by itself does not account for most of the interindividual variations in performance. In fact, in our 1991 manuscript (1), we also report that efficiency in a group of elite cyclists does not differ significantly from a group of good cyclists because of the high degree of individual variation in efficiency and fiber type. However, in a following study during which maximal oxygen consumption and lactate threshold were matched in a pairs of competitive cyclists, it was clear that performance power was significantly higher in subjects with greater gross efficiency and greater percentage of type I fibers (3). In fact, Armstrong makes this point in that his efficiency was only average when he was 21–22 yr despite the fact that he was already elite and world champion. However, his efficiency improved and he was able to generate 8% more power when cycling at a constant $\dot{V}O_2$ of 5.0 l/min.

We appreciate that winning the Tour de France requires tactical race understanding and motivational and psychological issues, among other things. However, nonphysiological factors and the winning of the Tour de France, although interesting, are not the focus of this investigation.

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

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David T. Martin
Marc J. Quod
Christopher J. Gore
Department of Physiology,
Australian Institute of Sport
Belconnen, ACT 2616, Australia
e-mail: david.martin@ausport.gov.au

REPLY

To the Editor: I appreciate this opportunity to answer the four points and address the terminology that Martin et al. find "confusing" (*point 3*).

1) Point 1: Timing of testing sessions. I agree that it is not possible to distinguish what aspects of Armstrong's training over the 7-yr period were related to his improved gross efficiency. Thus it was not discussed (4). Again, it can only be pointed out that he continued to train and his efficiency improved. Because the first measure in 1992 and the last measure in 1997 were both made in November when Armstrong's training was similar, the most appropriate design was indeed used to control for the possibility of seasonal variations in efficiency. The idea that cancer or chemotherapy might have improved Armstrong's efficiency cannot be determined from these data.

2) Point 2: Accuracy and reliability of efficiency. Oxygen uptake ($\dot{V}O_2$) and carbon dioxide production displayed a coefficient of variation of 0.87 and 0.92%, respectively, when measured on eight separate weekly occasions in a group of competitive cyclists in 1994 (6). Furthermore, the range (high minus low) of $\dot{V}O_2$ during these eight separate bouts averaged ±0.08 l/min (6). The point that bicycle ergometers can be inaccurate is well taken and appreciated. The Monark ergometer was chosen because it can be and was statically calibrated for each test. Martin et al. raise the possibility that the calculation of efficiency changed because of Monark ergometer aging instead of Armstrong aging (i.e., maturation). First of all, the mechanical components of Monark ergometer were kept in good condition with the regular cleaning and maintenance of the friction belt, flywheel, drive chain, and bearings, and thus, according to Maxwell et al. (8), it should not have "aged" significantly. Second, an "aging ergometer" according to Maxwell et al. will raise the oxygen cost and thus lower efficiency, which is the exact opposite of what was observed in Armstrong. who increased efficiency with age. The best dynamic calibration of the Monark 819 ergometer in my experience is derived when a pedal dynamometer is compared with simultaneous integration of forces and velocity of the flywheel. This dynamic calibration was performed on this exact "same" Monark ergometer using elite cyclists as subjects (3, 7). It was observed that ergometer power outputs between 20 and 400 W agreed with the right pedal dynamometer with a range of ±3%. 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 $\dot{V}O_2$ ($\dot{V}O_{2\,max}$) during the Tour de France is not needed to calculate watts per kilogram. The notion that endurance performance is related only to $\dot{V}O_{2\,max}$ 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).

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

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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 of the bicyclist who has now become the six-time consecutive Grand Champion of the Tour de France, at ages 27–32 yr. Maximal oxygen uptake ($\dot{V}O_{2\,max}$) 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% $\dot{V}O_{2\,max}$, 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 ($\dot{V}O_2$) 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 each of 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 $\dot{V}O_2$ (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 accuracy of 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 ($\dot{V}O_{2\,max}$) 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 $\dot{V}O_{2\,max}$ of 85 $ml \cdot kg^{-1} \cdot min^{-1}$. These estimations suggest that efficiency improved (21.2–23.1%; ~9%), while $\dot{V}O_{2\,max}$ rose (70–85 $ml \cdot kg^{-1} min^{-1}$; ~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.

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? Should it be other way?