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Delta efficiency calculation in Tour de France champion is wrong

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TO THE EDITOR: We previously raised concerns (6) about the methodology used to assess Lance Armstrong's muscle efficiency in the popular *Journal of Applied Physiology* paper entitled "Improved muscle efficiency displayed as Tour de France champion matures" (1). Subsequently, Coyle made available raw data from the January 1993 test that revealed several additional deviations from the published methodology. Coyle used a 20-min ergometer protocol (not 25 min), including 2- and 3-min stages where respiratory exchange ratios (RER) exceeded 1.00. An RER >1.00 invalidates use of the Lusk equations (5) to estimate energy expenditure.

A review of the raw data established that the published delta efficiency (DE) values in the Armstrong paper were calculated using the wrong equation. Coyle's published methodology (1) and that used by his group on several previous occasions (2, 4, 7) stipulates that linear regression ($y = mx + b$) be used to calculate DE, as the reciprocal of the slope from the relationship between the energy equivalent of oxygen uptake and cycling power output. However, Coyle calculated DE using the general formula $100 \times \Sigma(X \times Y) / \Sigma(X^2)$. This calculation is equivalent to linear regression using $y = mx$, which forces the regression line through the origin. Resting metabolic rate (RMR) as well as the cost of cycling without load (including the variable cost of ventilation and circulation) mandate that the regression line used to calculate DE cannot pass through the origin.

In their benchmark paper, Gaesser and Brooks (3) argue that DE, as the first derivative of the increase in caloric cost of exercise with respect to ordered increases in work, is a "floating base-line" method. Hence it is essential that the regression is not forced through zero when calculating DE. By employing $y = mx$ for each of the four data sets used to calculate DE, Coyle has assumed that Armstrong's RMR and cost of cycling without a load was not influenced by orchiectomy and chemo-

therapy, plus well-publicized weight fluctuations during the 7-year study.

Gross efficiency values reported by Coyle, which demonstrate an $r = 0.999$ correlation with his DE data, have been cogently dismissed by Gaesser and Brooks (3) as being of little value in understanding muscular efficiency. This interpretation is recognized by Coyle who notes on p. 2194 of his publication (1), "delta efficiency . . . provides the best reflection of power production . . . as it eliminates or minimizes the influence of the energy cost of unloaded cycling, ventilatory work, and other metabolic processes not directly linked to muscle power production."

Using the correct equation, we recalculated Armstrong's DE as 23.55% in January 1993 (23.02% if the 2-min stage is included), which exceeds the 23.12% value for the final test in November 1999. This is 8% higher than the reported value of 21.75%. The magnitude of this error warrants recalculation of the entire data set, but raw data from the remaining test sessions are not available from the author.

In conclusion, all of the published delta efficiency values are wrong. Thus there exists no credible evidence to support Coyle's conclusion that Armstrong's muscle efficiency improved.

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