## ARE WORLD-CLASS CYCLISTS REALLY MORE EFFICIENT?

**Dear Editor-in-Chief:**

**Metabolic efficiency is the ratio of mechanical work done by the muscles relative to the energy expended by the body (5), and the latter is calculated from the oxygen consumption ($\dot{V}O_2$) and substrate utilized (RER). Over the last 30 years, gross efficiency (GE) during cycling has been reported to range 18–22%.**

**Lucia et al. (10) recently presented GE from "world-class" road cyclists and reported an average GE of 24.5% with a peak of 28.1%. These data are unique and are indicative of either extreme physiological adaptations or methodological error.**

**Moseley et al. (11) reported average GE of 18.9% in world-class cyclists ($\dot{V}O_{2max}$ of 75.5 mL·kg$^{-1}$·min$^{-1}$) of similar caliber to those used by Lucia et al. In Moseley et al.'s study, the GE of professional cyclists varied from 17.7 to 22.3%, whereas others have reported GE between 18.4 and 22.5% (3,4,8). Measurements of GE in professional road cyclists, performed at the Australian Institute of Sport (AIS) over 15 yr, have generally ranged 20–22%. In a recent AIS study (9), the $\dot{V}O_2$-W relationship of world-class cyclists (73.0–78.3 mL·kg$^{-1}$·min$^{-1}$) was similar to regression equations published by other labs (7,13) and the ACSM (1). Regression equations for the seven professional male road cyclists indicate that $\dot{V}O_2$ at 385 W ranged 4.84–5.11 L·min$^{-1}$; values noticeably higher than those suggested by Lucia and colleagues (10). $\dot{V}O_{2max}$ data also demonstrate a large deviation from these regressions. Lucia and colleagues report exceptionally low and variable $\dot{V}O_{2max}$ at an admirable peak power output (4.8–5.7 L·min$^{-1}$ at ~500 W).**

**Efficiency reported by Lucia et al. (10) is also very high from a theoretical viewpoint. It is known that muscle efficiency during whole-body movements such as cycling is ~30% (2,12). The measurement of GE, however, is a whole-body measurement including other energy costs such as resting metabolic rate (~4 kJ·min$^{-1}$) that cannot be attributed to power output. GE is therefore likely less than 28% (as reported for one cyclist).**

**The cyclists in the study by Lucia et al. (10) rode at an average workload of 385 W or 23.1 kJ·min$^{-1}$. With a GE of 24.5%, this means that their energy expenditure was 94.3 kJ·min$^{-1}$. If we assume an average energy equivalent of 20.9 kJ·L$^{-1}$ $O_2$ (for RER = 0.90), they must have consumed 4.51 L $O_2$·min$^{-1}$ to ride at 385W, well below that predicted by well-established $\dot{V}O_2$-W regression equations (1,7,13) but higher than the reported values by Lucia et al.**

**One explanation for high GE is a systematic error in the measurement of $\dot{V}O_2$. A low $\dot{V}O_2$ overestimates GE. The authors used an automated breath-by-breath system (CPX/D; Medical Graphics; St. Paul, MN). A recent comparison of the CPX/D with automated Douglas bags revealed a significant underestimation (10.7–12.0%) of $\dot{V}O_2$ at workloads between 100 and 300 W (6). Interestingly, correction of Lucia et al.'s data for such an underestimation would result in GE in the normal range 20–22%.**

**Given that 1) the GE reported are outside the normal range, 2) the values reported are high from a theoretical viewpoint, 3) there seem to be calculation errors, and 4) that problems with the gas analysis equipment used in this study have been observed, it is likely that there is an error in the reported GE values. If, however, these values are correct, then some extremely interesting physiological adaptations may exist that require further study.**

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## COULD THE CORRELATION BETWEEN MAXIMAL OXYGEN UPTAKE AND "ECONOMY" BE SPURIOUS?

**Dear Editor-in-Chief:**

Recently, Lucia et al. (5) found negative relationships between maximal oxygen uptake ($\dot{V}O_{2max}$) and some measures of cycling "economy." These findings agreed with the work of previous researchers (8,10), who found a correlation between $\dot{V}O_{2max}$ and oxygen uptake ($\dot{V}O_2$) measured in response to submaximal running. Such findings deserve discussion given conflicting evidence from cross-sectional studies that trained individuals (with higher values of $\dot{V}O_{2max}$) are *more* economical than untrained subjects (7). We add to this discussion by providing evidence that the significant correlations found by Pate et al. (10) and Morgan and Daniels (8) could be spurious.

Soon after he developed the correlation coefficient (r), Pearson (11) recognized the dangers of investigating relationships between variables that have "common divisors." Consider three completely unrelated variables; x, y, and z. The ratio x:z will correlate with the ratio y:z, not through any "organic" link between x and y, but because z is a common divisor. Pate et al. (10) and Morgan and Daniels (8) expressed both $\dot{V}O_{2max}$ and submaximal $\dot{V}O_2$ relative to body mass. Therefore, body mass was a divisor of a ratio for both variables involved in the correlation analysis. A positive correlation larger than zero should have been obtained even with random values of $\dot{V}O_{2max}$ and submaximal $\dot{V}O_2$.

Pate et al. (10) and Morgan and Daniels (8) discussed the possible *physiological* mechanisms for a link between body mass, $\dot{V}O_{2max}$, and submaximal $\dot{V}O_2$, but the influence of the present *statistical* artifact on their data was not recognized. Surprisingly, even some (e.g., 6), but not all (e.g., 3), research specifically designed to examine the correlation between body mass and submaximal $\dot{V}O_2$ has expressed the latter variable relative to body mass. Body mass would be inherent in both x and y variables. This "relating a part to the whole" (1) would also result in spurious correlations (2,9).

The exact magnitude of a spurious correlation between ratios with a common divisor can be calculated using equations (4) or estimated by generating random data (12). For example, if Lucia et al. (5) had followed the procedures of Pate et al. (10) and Morgan and Daniels (8) and examined the relationship between $\dot{V}O_{2max}$ (mL·kg$^{-1}$·min$^{-1}$) and submaximal $\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$) with both variables expressed relative to body mass, an r of approximately 0.5 would have been obtained, on average, with completely random values of $\dot{V}O_2$ generated between 4.00 and 5.00 L·min$^{-1}$.

To the credit of Lucia et al. (5), only $\dot{V}O_{2max}$, and not submaximal $\dot{V}O_2$, was expressed relative to body mass. Nevertheless, one of the "economy" variables (W·L$^{-1}$) that was studied was derived from the measurement of $\dot{V}O_2$ at a power corresponding to 80% of $\dot{V}O_{2max}$. Therefore, it is apparent that $\dot{V}O_{2max}$ was not only one variable of interest but was also a factor involved in the "economy" variable. For the data of Lucia et al. (5), the r between $\dot{V}O_{2max}$ (mL·kg$^{-1}$·min$^{-1}$) and the power at 80% $\dot{V}O_{2max}$ can be calculated to be $-0.58$ ($P = 0.061$). Because the power at 80% $\dot{V}O_{2max}$ was the numerator (W) in the calculation of "economy," could it have been that $\dot{V}O_{2max}$ and "economy" were negatively related to each other, irrespective of any measurement of submaximal $\dot{V}O_2$?

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## RESPONSE

Dear Editor-in-Chief:

We acknowledge the constructive letter by Atkinson et al. (1) and their interest in following our work, especially related to statistical matters. We understand that the relationship between two variables (ratios) can be spurious if one of them is the numerator or divisor of the other, and correlation coefficients must be interpreted with caution.

We believe, however, that our main findings were not affected by the aforementioned artifact. The fact that we found a significant negative correlation between absolute values of economy/efficiency (i.e., not divided by body mass) and $\dot{V}O_{2max}$ corrected by body mass ($mL \cdot kg^{-1} \cdot min^{-1}$ or $mL \cdot kg^{-0.32} \cdot min^{-1}$) seem to reflect a physiological phenomenon behind our data. Moreover, correlation coefficients between economy/efficiency and $\dot{V}O_{2max}$ were lower (and with a higher $P$ value) when $\dot{V}O_{2max}$ was not corrected by body mass (i.e., expressed as $mL \cdot min^{-1}$).

We can answer the last question posed by Atkinson et al. by reporting the correlation coefficients between $\dot{V}O_{2max}$ ($mL \cdot min^{-1}$ and $mL \cdot kg^{-1} \cdot min^{-1}$) and economy data ($W \cdot L^{-1} \cdot min^{-1}$) in nine trained cyclists pedalling at a fixed load (~ 70% of their peak power output) for a total of 20 min (unpublished study). One of the coauthors of Atkinson's letter, Dr. Richard Davison, participated with us in data collection (July 2002, Exercise Physiology Laboratory of the European University of Madrid). The subjects were tested with both a conventional and nonconventional pedalling system.

No significant correlation was found with either pedalling system between $\dot{V}O_{2max}$ ($mL \cdot min^{-1}$ or $mL \cdot kg^{-1} \cdot min^{-1}$) and economy, and the values of the coefficient of correlation (r) were considerably lower than those found in professional top-level cyclists riding for 20 min at a fixed load (~74% of their peak power output) (3) (conventional system: $r = 0.497$ and $P = 0.17$ for $\dot{V}O_{2max}$ ($mL \cdot min^{-1}$) vs economy, and $r = 0.04$ and $P = 0.92$ for $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) vs economy; nonconventional system: $r = -0.445$ and $P = 0.23$ for $\dot{V}O_{2max}$ ($mL \cdot min^{-1}$) vs economy, and $r = -0.376$ and $P = 0.32$ for $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) vs economy). Further, values of r and $P$ considerably decreased and increased, respectively, with allometric scaling of $\dot{V}O_{2max}$, which is in contrast with our previous findings with professional cyclists (3). Thus, the specific characteristics of the athletes' group we chose (3) has, most likely, influenced the correlations we reported.

The main message of our paper (3) is that, in the natural selection process to succeed in world-class professional cycling, relatively low $\dot{V}O_{2max}$ values can be compensated for by a high economy/efficiency. One must consider that we found a significant correlation between two variables that are determined by different physiological phenomena: $\dot{V}O_{2max}$ is mainly limited by the maximal capacity of the cardiac pump (4), whereas economy is largely dependent on the distribution of efficient Type I fibers in knee extensor muscles (2).

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