Article title (English): Underestimation of Economy from Incremental Tests: Implications for Practitioners.

Article title (Francais): Sous estimation de l'économie de la locomotion lors d'un test incrémental: implications pour les praticiens

Submission type: Brief Note

Mark Tabrett [1]., Cain C. T. Clark [2,3]., Stephen C. How [1]., Stephen B. Draper [2,]

[1] University of Gloucestershire, Oxstalls Campus, Longlevens, Gloucestershire, GL2 9HW UK.

[2] University Centre Hartpury, Higher Education Sport, Gloucestershire, GL19 3BE, UK.

[3] Faculty of Health and Life Sciences, Coventry University, Coventry, CV1 5FB, UK.

Corresponding author: Dr. Cain C. T. Clark, Faculty of Health and Life Sciences, Coventry University, Coventry, CV1 5FB, UK., cain.clark@coventry.ac.uk, +447471 898 098.

Running head: Underestimation of Exercise Economy

Manuscript Character Count: 7,377

Number of Figures and Tables: 1 figure; 1 tables

Summary (English)

Purpose

Current practices for estimating exercise economy using an extrapolation of sub-gas exchange threshold (GET), and to a lesser degree supra-GET, data will likely result an underestimation of actual economy, however, this is yet to be empirically demonstrated. Despite contentions, these protocols remain in widespread use. Therefore, the aim of the present study was to investigate whether estimation of exercise economy from moderate only, and moderate and heavy intensity exercise underestimates actual oxygen cost.

Summary of Facts and Results

Twelve recreationally active males (mean ± SD; age 29±9y, height 1.81±0.07m, mass 81.4±10kg) volunteered for this study. Following a maximal ramp test to determine the $\dot{V}O_{2peak}$, peak power (W_{peak}), $\dot{V}O_2$ and power output at GET, participants completed a sub-GET only, a sub/supra-GET (both five-stage incremental tests), and a fixed WR protocol (10 min duration at 75% Δ). Economy was determined by extrapolation of sub- and sub/supra-GET $\dot{V}O_2$ and directly measured $\dot{V}O_2$ at 75% Δ. Within-subjects ANOVA was performed to identify differences in economy between sub-GET only, sub/supra-GET, and fixed WR protocols. Significant effects between the predicted values compared to the measured value were investigated post hoc using Bonferroni corrected paired t-tests.

There was a significant effect of protocol on $\dot{V}O_2$ and economy ($P<0.001$, $\eta_p^2 = 0.645$), where both methods of estimation underestimated the actual oxygen cost. In addition, estimation-using sub-GET data was significantly lower than sub/supra-GET ($P<0.05$).

Conclusion

The large error obtained by extrapolating sub-GET exercise intensities for the purpose of estimating exercise economy needs to be acknowledged, as does the concomitant, albeit reduced, error that remains when incorporating supra-GET data. Exercise scientists and practitioners should adopt more appropriate testing protocols such as serial assessments, up-to and including race pace, to accurately assess economy.

Key words: Exercise; Economy; Prediction; O_2 Cost; Measurement

Résumé (Francais)

Introduction

Les pratiques actuelles pour estimer l'économie de la locomotion qui utilisent des valeurs sous maximales et/ou parfois supérieures au seuil ventilatoire restent largement utilisés mais présentent le risque d'aboutir à une sous estimation de l'économie de la locomotion. Le but de la présente étude est d'examiner si l'estimation de l'économie à partir de valeurs d'exercice modéré seules ou d'exercice modéré et supérieur au seuil ventialtoire sous estiment le coût réel de l'exercice.

Résumé des faits et des résultats

Douze hommes (29±9y, 1.81±0.07m, 81.4±10kg) se sont portés volontaires pour cette étude. Après un test incrémental maximal afin de déterminer le VO2pic, la puissance maximale (Wpeak) et la puissance au seuil ventilatoire (GET), les participants ont réalisé exercice à une intensité inférieure à GET et une série de tests d'intensités inférieures ou supérieures à GET ainsi qu'un exercice à une intensité fixe de 75% de la différence entre la puissance à GET et à VO2pic. Une ANOVA intra-sujets a été réalisée pour identifier les différences d'économie entre les protocoles. Les différences significatives entre la valeur prédite et la valeur mesurée ont été étudiés à l'aide d'un test t pour échantillons appariés après correction de Bonferroni. Un effet significatif du type de protocole a été identifié sur l'économie de locomotion ($P<0.001$, $eta^2 = 0.645$). Les deux méthodes sous estiment l'économie de la locomotion, par ailleurs l'estimation issue du test sous maximal seul était significativement plus faible celle issue de données des exercices inférieurs et supérieures à GET.

Conclusion

Dans tous les cas les données issues de tests d'intensités inférieures ou supérieures à GET sous estiment la valeur réelle du coût de la locomotion. Les praticiens doivent utiliser des protocoles de test plus appropriés, tels que des évaluations multiples, pour évaluer avec précision l'économie de la locomotion.

Mots-clés: exercice; économie; coût en oxygène; locomotion

Article title (English): Underestimation of Economy from Incremental Tests: Implications for Practitioners.

Article title (Francais): Sous estimation de l'économie de la locomotion lors d'un test incrémental: implications pour les praticiens

Submission type: Brief Note

Running head: Underestimation of Exercise Economy

Manuscript Character Count: 6,830

Number of Figures and Tables: 1 figure; 1 tables

Summary (English)

Purpose

Current practices for estimating exercise economy using an extrapolation of sub-gas exchange threshold (GET), and indeed supra-GET, data will likely result an underestimation of actual economy, however, is yet to be empirically demonstrated. Despite contentions, these protocols remain in widespread use. Therefore, the aim of the present study was to investigate whether estimation of exercise economy from moderate only, and moderate and heavy intensity exercise underestimates actual oxygen cost.

Summary of Facts and Results

Twelve recreationally active males (mean ± SD; age 29±9y, height 1.81±0.07m, mass 81.4±10kg) volunteered for this study. Following a maximal ramp test to determine the $\dot{V}O_{2peak}$, peak power (W_{peak}), $\dot{V}O_2$ and power output at GET, participants completed a sub-GET only, a sub/supra-GET (both five-stage incremental tests), and a fixed WR protocol (10 min duration at 75% Δ). Economy was determined by extrapolation of sub- and sub/supra-GET $\dot{V}O_2$ and directly measured $\dot{V}O_2$ at 75% Δ. Within-subjects ANOVA was performed to identify differences in economy between sub-GET only, sub/supra-GET, and fixed WR protocols. Significant effects between the predicted values compared to the measured value were investigated post hoc using Bonferroni corrected paired t-tests.

There was a significant effect of protocol on $\dot{V}O_2$ and economy ($P<0.001$, $\eta_p^2 = 0.645$), where both methods of estimation underestimated the actual oxygen cost. In addition, estimation-using sub-GET data was significantly lower than sub/supra-GET ($P<0.05$).

Conclusion

The large error obtained by extrapolating sub-GET exercise intensities for the purpose of estimating exercise economy needs to be acknowledged, as does the concomitant, albeit reduced, error that remains when incorporating supra-GET data. Exercise scientists and practitioners should adopt more appropriate testing protocols such as serial assessments, up-to and including race pace, to accurately assess economy.

Key words: Exercise; Economy; Prediction; O_2 Cost; Measurement

Résumé (Francais)

Introduction

Les pratiques actuelles pour estimer l'économie de la locomotion qui utilisent des valeurs sous maximales et/ou parfois supérieures au seuil ventilatoire restent largement utilisés mais présentent le risque d'aboutir à une sous estimation de l'économie de la locomotion. Le but de la présente étude est d'examiner si l'estimation de l'économie à partir de valeurs d'exercice modéré seules ou d'exercice modéré et supérieur au seuil ventialtoire sous estiment le coût réel de l'exercice.

Résumé des faits et des résultats

Douze hommes (29±9y, 1.81±0.07m, 81.4±10kg) se sont portés volontaires pour cette étude. Après un test incrémental maximal afin de déterminer le VO2pic, la puissance maximale (Wpeak) et la puissance au seuil ventilatoire (GET), les participants ont réalisé exercice à une intensité inférieure à GET et une série de tests d'intensités inférieures ou supérieures à GET ainsi qu'un exercice à une intensité fixe de 75% de la différence entre la puissance à GET et à VO2pic. Une ANOVA intra-sujets a été réalisée pour identifier les différences d'économie entre les protocoles. Les différences significatives entre la valeur prédite et la valeur mesurée ont été étudiés à l'aide d'un test t pour échantillons appariés après correction de Bonferroni. Un effet significatif du type de protocole a été identifié sur l'économie de locomotion ($P<0.001$, $eta^2 = 0.645$). Les deux méthodes sous estiment l'économie de la locomotion, par ailleurs l'estimation issue du test sous maximal seul était significativement plus faible celle issue de données des exercices inférieurs et supérieures à GET.

Conclusion

Dans tous les cas les données issues de tests d'intensités inférieures ou supérieures à GET sous estiment la valeur réelle du coût de la locomotion. Les praticiens doivent utiliser des protocoles de test plus appropriés, tels que des évaluations multiples, pour évaluer avec précision l'économie de la locomotion.

Mots-clés: exercice; économie; coût en oxygène; locomotion

Introduction

Economy is defined as the steady-state oxygen requirement ($\dot{V}O_2$) for a given submaximal work rate (WR) or to cover a given distance [1, 2]. A superior economy is considered important as this allows endurance athletes to perform at a faster race pace for the same $\dot{V}O_2$ requirement, differentiating between athletes of comparable $\dot{V}O_{2max}$ [2, 3]. Economy is traditionally measured by directly calculating the $\dot{V}O_2$ at a fixed WR [4], predicted using linear regression of the $\dot{V}O_2$-WR relationship determined from sub-GET WRs [5], which takes no account of the slow component of $\dot{V}O_2$, or utilizing a full-range of WRs. By utilizing a full range of WRs, some account is taken of the slow component; however, the full-response is unlikely to emerge within the timeframe of normal testing bouts [6]. The inference of economy by extrapolation is based on the concept of a linear $\dot{V}O_2$ kinetic response to increasing WRs ($\dot{V}O_2$-WR relationship) [7]. The $\dot{V}O_2$ kinetic response to a constant-load moderate intensity WR has been well described as mono-exponential and reaching steady state within 2-3 min [7, 8]. However, $\dot{V}O_2$ kinetics is more complex above the GET, where steady state is both delayed and elevated above that predicted from sub-GET work rates (slow component) [9]. This additional complexity is one reason for the Foster and Lucia [3] assertion that sub-GET extrapolation to assess economy is preferential. However, economy determined from sub-GET work rates, (where the slow component is removed, and extrapolated up to and exceeding race pace) includes data likely to be on a different slope resulting in a systematic underestimation of actual economy. Whilst even incorporating sub- and supra-GET intensities will likely not allow the slow component to fully emerge (due to length of stages), again underestimating economy. Furthermore, given that training and competition inevitably occurs at supra-GET intensities, this raises concerns about current practices for the assessment of economy, which, to the authors' knowledge, has not been empirically investigated. Therefore, the aim of the present study was to investigate whether estimation of exercise economy from moderate only, and moderate and heavy intensity exercise underestimates actual oxygen cost.

Methods

Participants

Twelve male recreationally active participants (mean ± SD; age 29 ± 9 y, height 1.81 ± 0.07 m, mass 81.4 ± 10 kg) volunteered to participate in this study, which had been approved by the institutional research ethics committee, and in accordance with the Declaration of Helsinki. Written informed consent was obtained prior to data collection. Participants were instructed to report to the laboratory in a well-hydrated, rested state, and having abstained from alcohol and caffeine for the preceding 24 and 6 h, respectively.

Protocol

Participants visited the laboratory on four separate days. The first visit consisted of a maximal ramp test to determine the $\dot{V}O_{2peak}$, peak power (W_{peak}), $\dot{V}O_2$ and power output at GET, using an electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, NL). On each subsequent visit, participants completed a sub-GET only, a sub/supra-GET, and a fixed WR protocol, in a randomized order. The sub-GET only protocol consisted of five WR stages of six min duration at moderate intensity. The sub/supra-GET protocol consisted of five WR stages of six min in duration across a broad range of WRs from 50W to 85% Δ (Δ is the difference between power at GET and $\dot{V}O_{2peak}$). The fixed WR protocol consisted of 10 minutes cycling at 75% Δ [10].

For all tests, participants wore a nose clip and breathed through a low-dead-space (90 mL), low-resistance (5.5 cmH_2O at 510 $L.min^{-1}$) mouthpiece and impeller turbine transducer assembly (Jaeger Triple V, Jaeger GmbH, Hoechburg, Germany). Inspired and expired gas volume and concentration signals were continuously sampled and drawn from the mouthpiece through a 2m sampling line (0.5 mm internal diameter) to a quadrupole mass spectrometer system (EX671, Ferraris Respiratory Europe Ltd., Hertford), where they were analyzed for O_2, CO_2 and N_2. Expired volumes were determined using a turbine volume transducer (Interface Associates, Alifovieja, US).

Data Analyses

For all tests, breath-by-breath $\dot{V}O_2$ data were initially examined to exclude errant breaths caused by coughing, swallowing etc., and those values lying more than 4 SD from the local mean were removed [11]. Subsequently, breath-by-breath data were linearly interpolated to second-by-second data and time aligned to the start of exercise. Data from the maximal ramp test were used to derive $\dot{V}O_{2peak}$ and the $\dot{V}O_2$ at GET. The sub-GET only protocol initial stage was set at 50 W and the subsequent stages were calculated to produce four equal WR steps between 50 W and 95% of the power at GET. The sub/supra-GET protocol initial stage was set at 50 W, with subsequent stages calculated to produce four equal WR steps between 50 W and 85% Δ. The fixed WR protocol consisted of cycling for 10 min at a WR of 75% Δ of power output at $\dot{V}O_{2peak}$.

Statistical analyses

Within-subjects ANOVA was performed to identify differences between sub-GET only, sub/supra-GET, and fixed WR protocols. A significant effect between the predicted values compared to the measured value was investigated post hoc using Bonferroni corrected paired t-tests. Statistical significance was set as $P < 0.05$, and effect size was reported using partial Eta squared (η_p^2). Data were presented as mean ± SD unless otherwise stated.

Results

There was a significant effect of protocol on $\dot{V}O_2$ and economy ($P<0.001$, $\eta_p^2 = 0.645$), where both methods of estimation underestimated the actual oxygen cost. The magnitude of this error was significantly larger when using the sub-GET method for estimation. These results are shown in Table 1. The mean $\dot{V}O_2$ response during the 10-min fixed WR at 75% is plotted in Figure 1 together with the predicted $\dot{V}O_2$ from both methods of estimation from the incremental tests.

Table 1 about here

Figure 1 about here

Discussion

The principal findings of this investigation were that, 1) there was a significant and large underestimation of economy when using sub-GET extrapolation, and 2) this underestimation persists, although to a lesser degree, with sub/supra GET extrapolation.

This study demonstrated that predictive regressions systematically underestimated the value of economy at 75% Δ, confounding the assertion that this method should be considered the standard approach for exercise scientists and practitioners [3]. This was a pragmatic topic of investigation, particularly given the high-profile and widespread utilization of sub-GET data to infer exercise economy for elite and sub-elite athletes [3, 12], therein providing athletes and coaches with inaccurate values, pivotal for training and competition. Similarly, practitioners should question literature reported reference values, which are likely not comparable [12].

This study highlights the need for practitioners and exercise scientists to acknowledge the spurious inferences obtained by extrapolating sub-GET exercise intensities, or indeed any regression at all. Given that training and competition will inevitably occur at supra-GET intensities, practitioners seeking to assess economy should instead opt for sequential tests at a range of WRs, including one at race specific pace.

References

[1] Mooses M, Mooses K, Haile DW, Durussel J, Kaasik P, Pitsiladis YP. Dissociation between running economy and running performance in elite Kenyan distance runners. Journal of Sports Sciences. 2015;33:136-44.

[2] Morgan DW, Craib M. Physiological aspects of running economy. Medicine and Science of Sports and Exercise. 1992;24:456-61.

[3] Foster C, Lucia A. Running Economy: The Forgotten Factor in Elite Performance. Sports medicine. 2007;37:316-9.

[4] Joyner MJ. Modelling: optimal marathon performance on the basis of physiological factors. Journal of applied physiology. 1991;70:683-7.

[5] Daniels JT, Daniels N. Running economy of elite male and elite female runners. Medicine and Science of Sports and Exercise. 1992;24:483-9.

[6] Bangsbo J. Oxygen Deficit: A measure of the anaerobic energy production during intense exercise. Canadian Journal of Applied Physiology. 1996;21:350-63.

[7] Whipp BJ, Ward SA. Physiological Determinants of Pulmonary Gas-Exchange Kinetics during Exercise. Medicine and science in sports and exercise. 1990;22:62-71.

[8] Burnley M, Jones AM. Oxygen uptake kinetics as a determinant of sports performance. European journal of sport science. 2007;7:63-79.

[9] Bearden SE, Moffatt RJ. VO(2) kinetics and the O(2) deficit in heavy exercise. Journal of applied physiology. 2000;88:1407-12.

[10] Sherman NW, Jackson AS. Utilizing regression analysis to evaluate running economy. Measurement in physical education and exercise science. 1998;2:165-76.

[11] Whipp BJ, Ward SA, Lamarra N, Davis JA, Wasserman K. Parameters of Ventilatory and Gas-Exchange Dynamics during Exercise. Journal of applied physiology. 1982;52:1506-13.

[12] Jones AM. The Physiology of the World Record Holder for the Women's Marathon. International Journal of Sports Science and Coaching. 2006;1:100-16.

Figure caption

Figure 1: The mean $\dot{V}O_2$ response during fixed WR cycling at 75% Δ, with the mean predicted $\dot{V}O_2$ at 75% Δ from the two regression methods (estimated$_{subGET}$ is the solid line and estimated$_{sub/supraGET}$ is the broken line).

Tables

Table 1: Mean (SD) values for economy and $\dot{V}O_2$ for all protocols, together with the differences from the measured $\dot{V}O_2$ for each estimate. Also shown are the results of the post hoc test.

	Economy ($ml.min^{-1}.W^{-1}$)	$\dot{V}O_2$ ($L.min^{-1}$)	Diff from measured ($L.min^{-1}$)
Estimated(subGET)	12.2 (1.5)	2.89 (0.41)	0.54 (0.31)*†
Estimated(sub/supraGET)	13.5 (1.0)	3.21 (0.47)	0.22 (0.21)*
Measured	14.4 (0.6)	3.43 (0.45)	-

*significantly lower than measured ($P<0.05$); †significantly lower than estimated$_{sub/supraGET}$

Figure