

Underestimation of Economy from Incremental Tests: Implications for Practitioners

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5 **incrémental: implications pour les praticiens**

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8

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33 **Summary (English)**

34 Purpose

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

41 Summary of Facts and Results

42 Twelve recreationally active males (mean \pm SD; age 29 \pm 9y, height 1.81 \pm 0.07m, mass
43 81.4 \pm 10kg) volunteered for this study. Following a maximal ramp test to determine the $\dot{V}O_{2\text{peak}}$,
44 peak power (W_{peak}), $\dot{V}O_2$ and power output at GET, participants completed a sub-GET only, a
45 sub/supra-GET (both five-stage incremental tests), and a fixed WR protocol (10 min duration
46 at 75% Δ). Economy was determined by extrapolation of sub- and sub/supra-GET $\dot{V}O_2$ and
47 directly measured $\dot{V}O_2$ at 75% Δ . Within-subjects ANOVA was performed to identify
48 differences in economy between sub-GET only, sub/supra-GET, and fixed WR protocols.
49 Significant effects between the predicted values compared to the measured value were
50 investigated post hoc using Bonferroni corrected paired t-tests.

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

54

55 Conclusion

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

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62 **Key words:** Exercise; Economy; Prediction; O₂ Cost; Measurement

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69 **Résumé (Français)**

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71

72 Les pratiques actuelles pour estimer l'économie de la locomotion qui utilisent des valeurs sous
73 maximales et/ou parfois supérieures au seuil ventilatoire restent largement utilisés mais
74 présentent le risque d'aboutir à une sous estimation de l'économie de la locomotion. Le but de
75 la présente étude est d'examiner si l'estimation de l'économie à partir de valeurs d'exercice
76 modéré seules ou d'exercice modéré et supérieur au seuil ventialtoire sous estiment le coût réel
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78

79 **Résumé des faits et des résultats**

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81 Douze hommes (29±9y, 1.81±0.07m, 81.4±10kg) se sont portés volontaires pour cette étude.
82 Après un test incrémental maximal afin de déterminer le VO₂pic, la puissance maximale
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93

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96 Dans tous les cas les données issues de tests d'intensités inférieures ou supérieures à GET sous
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168

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171 Dans tous les cas les données issues de tests d'intensités inférieures ou supérieures à GET sous
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174 l'économie de la locomotion.

175

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

177 **Introduction**

178 Economy is defined as the steady-state oxygen requirement ($\dot{V}O_2$) for a given submaximal
179 work rate (WR) or to cover a given distance^{1,2}. A superior economy is considered important
180 as this allows endurance athletes to perform at a faster race pace for the same $\dot{V}O_2$ requirement,
181 differentiating between athletes of comparable $\dot{V}O_{2max}$ ^{2,3}. Economy is traditionally measured
182 by directly calculating the $\dot{V}O_2$ at a fixed WR⁴, predicted using linear regression of the $\dot{V}O_2$ -
183 WR relationship determined from sub-GET WRs⁵, which takes no account of the slow
184 component of $\dot{V}O_2$, or utilizing a full-range of WRs. By utilizing a full range of WRs, some
185 account is taken of the slow component; however, the full-response is unlikely to emerge within
186 the timeframe of normal testing bouts⁶. The inference of economy by extrapolation is based
187 on the concept of a linear $\dot{V}O_2$ kinetic response to increasing WRs ($\dot{V}O_2$ -WR relationship)⁷.
188 The $\dot{V}O_2$ kinetic response to a constant-load moderate intensity WR has been well described
189 as mono-exponential and reaching steady state within 2-3 min^{7,8}. However, $\dot{V}O_2$ kinetics is
190 more complex above the GET, where steady state is both delayed and elevated above that
191 predicted from sub-GET work rates (slow component)⁹. This additional complexity is one
192 reason for the Foster and Lucia³ assertion that sub-GET extrapolation to assess economy is
193 preferential. However, economy determined from sub-GET work rates, (where the slow
194 component is removed, and extrapolated up to and exceeding race pace) includes data likely to
195 be on a different slope resulting in a systematic underestimation of actual economy. Whilst
196 even incorporating sub- and supra-GET intensities will likely not allow the slow component to
197 fully emerge (due to length of stages), again underestimating economy. Furthermore, given
198 that training and competition inevitably occurs at supra-GET intensities, this raises concerns
199 about current practices for the assessment of economy, which, to the authors' knowledge, has
200 not been empirically investigated. Therefore, the aim of the present study was to investigate
201 whether estimation of exercise economy from moderate only, and moderate and heavy intensity
202 exercise underestimates actual oxygen cost.

203 **Methods**

204 **Participants**

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

211 **Protocol**

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

221 For all tests, participants wore a nose clip and breathed through a low-dead-space (90 mL),
222 low-resistance (5.5 cmH₂O at 510 L.min⁻¹) mouthpiece and impeller turbine transducer
223 assembly (Jaeger Triple V, Jaeger GmbH, Hoechburg, Germany). Inspired and expired gas

224 volume and concentration signals were continuously sampled and drawn from the mouthpiece
225 through a 2m sampling line (0.5 mm internal diameter) to a quadrupole mass spectrometer
226 system (EX671, Ferraris Respiratory Europe Ltd., Hertford), where they were analyzed for O₂,
227 CO₂ and N₂. Expired volumes were determined using a turbine volume transducer (Interface
228 Associates, Alifovieja, US).

229 **Data Analyses**

230 For all tests, breath-by-breath $\dot{V}O_2$ data were initially examined to exclude errant breaths
231 caused by coughing, swallowing etc., and those values lying more than 4 SD from the local
232 mean were removed ¹¹. Subsequently, breath-by-breath data were linearly interpolated to
233 second-by-second data and time aligned to the start of exercise. Data from the maximal ramp
234 test were used to derive $\dot{V}O_{2peak}$ and the $\dot{V}O_2$ at GET. The sub-GET only protocol initial stage
235 was set at 50 W and the subsequent stages were calculated to produce four equal WR steps
236 between 50 W and 95% of the power at GET. The sub/supra-GET protocol initial stage was set
237 at 50 W, with subsequent stages calculated to produce four equal WR steps between 50 W and
238 85% Δ . The fixed WR protocol consisted of cycling for 10 min at a WR of 75% Δ of power
239 output at $\dot{V}O_{2peak}$.

240

241 **Statistical analyses**

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

247

248 **Results**

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

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256 ***Table 1 about here***

257 ***Figure 1 about here***

258

259 **Discussion**

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

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

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

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278 **References**

- 279 [1] Mooses M, Mooses K, Haile DW, Durussel J, Kaasik P, Pitsiladis YP. Dissociation between
280 running economy and running performance in elite Kenyan distance runners. *Journal of Sports*
281 *Sciences*. 2015;33:136-44.
- 282 [2] Morgan DW, Craib M. Physiological aspects of running economy. *Medicine and Science of Sports*
283 *and Exercise*. 1992;24:456-61.
- 284 [3] Foster C, Lucia A. Running Economy: The Forgotten Factor in Elite Performance. *Sports*
285 *medicine*. 2007;37:316-9.
- 286 [4] Joyner MJ. Modelling: optimal marathon performance on the basis of physiological factors.
287 *Journal of applied physiology*. 1991;70:683-7.
- 288 [5] Daniels JT, Daniels N. Running economy of elite male and elite female runners. *Medicine and*
289 *Science of Sports and Exercise*. 1992;24:483-9.
- 290 [6] Bangsbo J. Oxygen Deficit: A measure of the anaerobic energy production during intense
291 exercise. *Canadian Journal of Applied Physiology*. 1996;21:350-63.
- 292 [7] Whipp BJ, Ward SA. Physiological Determinants of Pulmonary Gas-Exchange Kinetics during
293 Exercise. *Medicine and science in sports and exercise*. 1990;22:62-71.
- 294 [8] Burnley M, Jones AM. Oxygen uptake kinetics as a determinant of sports performance. *European*
295 *journal of sport science*. 2007;7:63-79.
- 296 [9] Bearden SE, Moffatt RJ. VO(2) kinetics and the O(2) deficit in heavy exercise. *Journal of applied*
297 *physiology*. 2000;88:1407-12.
- 298 [10] Sherman NW, Jackson AS. Utilizing regression analysis to evaluate running economy.
299 *Measurement in physical education and exercise science*. 1998;2:165-76.
- 300 [11] Whipp BJ, Ward SA, Lamarra N, Davis JA, Wasserman K. Parameters of Ventilatory and Gas-
301 Exchange Dynamics during Exercise. *Journal of applied physiology*. 1982;52:1506-13.
- 302 [12] Jones AM. The Physiology of the World Record Holder for the Women's Marathon. *International*
303 *Journal of Sports Science and Coaching*. 2006;1:100-16.

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321 **Figure caption**

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323 **Figure 1:** The mean $\dot{V}O_2$ response during fixed WR cycling at 75% Δ , with the mean predicted
324 $\dot{V}O_2$ at 75% Δ from the two regression methods (estimated_{subGET} is the solid line and
325 estimated_{sub/supraGET} is the broken line).

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369 **Tables**

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371 Table 1: Mean (SD) values for economy and $\dot{V}O_2$ for all protocols, together with the differences
 372 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)	-

373 *significantly lower than measured (P<0.05); †significantly lower than estimated_{sub/supraGET}

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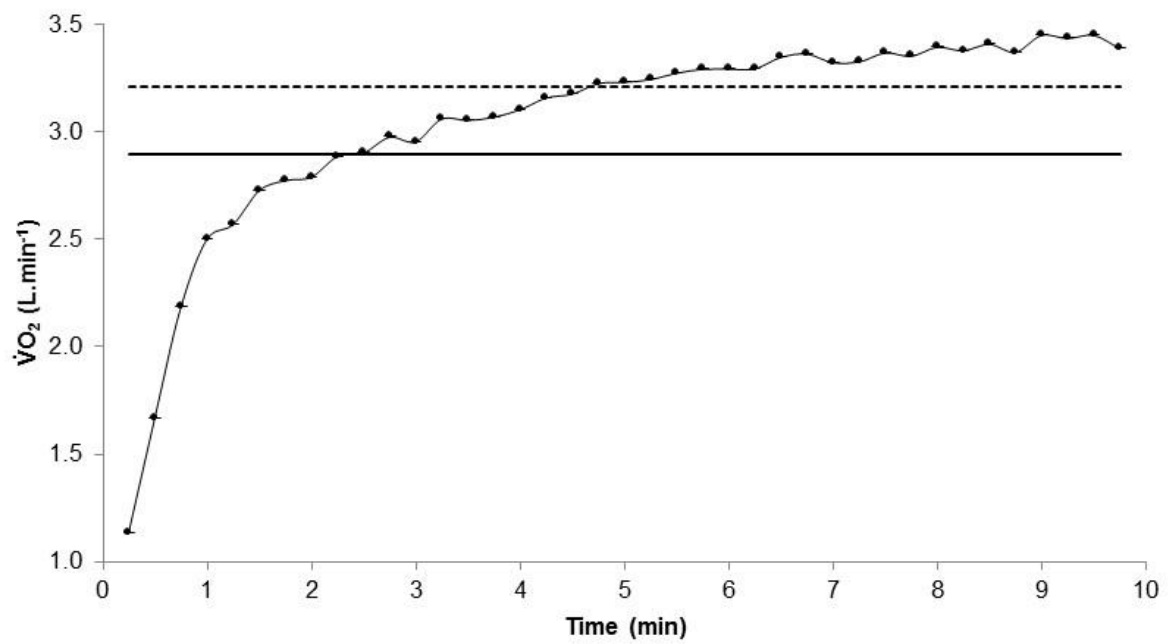
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413 **Figure**
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