Artefactual Incidence of VO2 Plateau and VO2max in Historical Studies: Time to Move on Barr, Rachel; Clark, C. C. T.; Corbett, Jo; Draper, Stephen

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 Time to Move on

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#### 34 **1.0 Summary (English)**

- 35 Artefactual Incidence of  $\dot{VO}_2$  Plateau and  $\dot{VO}_{2max}$  in Historical Studies: Time to Move on
- 36 Purpose

Contemporary understanding of the time course of oxygen uptake suggests that traditional discontinuous tests are of insufficient duration to elicit a fully developed  $\dot{V}O_2$  response.

- discontinuous tests are of insufficient duration to elicit a fully developed  $\dot{VO}_2$  response. However, this remains to be empirically demonstrated. Thus, the aims of the present study were
- 40 (1) to investigate whether early  $\dot{V}O_{2max}$  assessments underestimated actual  $\dot{V}O_2$ , and (2) to
- 41 investigate whether the apparent  $\dot{V}O_2$  plateau observed in classic studies was an artefact of
- 42 measuring in a non-steady state.
- 43 Summary of Facts and Results
- 44 Twelve males (age  $28 \pm 7$  y,  $1.78 \pm 0.05$  m,  $80 \pm 11$  kg) each completed a constant speed
- 45 discontinuous test. The study design replicated the increasing gradient discontinuous test used
- by Taylor, et al. <sup>1</sup>.  $VO_2$  data were averaged during the 1.75-2.75 min ( $VO_{2.Taylor}$ ) time point and
- 47 the final minute of each test ( $\dot{VO}_{2.Final}$ ). A paired samples *t*-test was used to evaluate differences
- 48 in  $\dot{V}O_{2peak.Taylor}$  and  $\dot{V}O_{2peak.Final}$
- 49 The  $\dot{V}O_{2peak.Final}$  was found to be significantly higher than  $\dot{V}O_{2peak.Taylor}$  (*P*<0.001, *d* = 1.18).
- 50 The slope of the  $\dot{V}O_2$  response, calculated from the last completed gradient for each participant
- 51 was significantly different from zero during the 1.75-2.75 min (Taylor: P=0.009, d = 1.58;
- 52 Final: *P*=0.02, *d* = 0.29).
  53
- 54 Conclusion
- $\dot{VO}_2$  plateau in historical studies was artefactual. Further investigation, without the fallacious

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- assumptions of historical studies, may enable exercise physiologists and practitioners to
- 57 determine which combination of exercise protocol and method of data acquisition is most
- 58 conducive to elicit and detect a  $\dot{VO}_2$  plateau.
- 59
- 60 Key words: Maximal; Oxygen uptake; Plateau; Discontinuous; Measurement
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72 Le plateau définissant la VO2max dans les études classiques était-il un artefact

73 **Résumé (Français)** 

74 Introduction

Les données actuelles sur la cinétique dans le temps de la consommation d'oxygène portent à penser que les tests discontinus traditionnels sont d'une durée insuffisante pour solliciter pleinement la réponse de  $\dot{V}O_2$ . Cela reste cependant à démontrer expérimentalement. Les objectifs de la présente étude étaient donc : (1) d'examiner si les évaluations précoces de  $\dot{V}O_{2max}$  sous-estimaient la  $\dot{V}O_2$  et (2) d'étudier si le plateau apparent de  $\dot{V}O_2$  observé dans les études classiques était un artefact de mesure représentant un état non stationnaire.

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83 **Résumé des faits et des résultats:** 

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Bouze sujets de sexe masculin (28 ± 7 ans, 1,78 ± 0,05 m, 80 ± 11 kg) ont chacun effectué
un test incrémental par paliers à vitesse constante de pédalage. Ce protocole visait à
reproduire le test par paliers à incréments constants utilisé par Taylor. Les données de
VO2 ont été moyennées pendant l'intervalle de temps 1.75-2.75 min (VO2.Taylor) et à la
minute finale de chaque test (VO2.Finale). Un test t pour échantillons appariés a été utilisé
pour évaluer les différences de VO2pic.Taylor et de VO2pic.Finale.

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La VO<sub>2peak,Finale</sub> s'est révélée significativement plus élevée que la VO<sub>2peak,Taylor</sub> (P <0,001,</li>
d = 1,18). La pente de la réponse de VO<sub>2</sub>, calculée à partir du dernier icrément obtenu
chez chaque participant était significativement différente de zéro pendant les intervalles
1,75-2,75 min (Taylor: P = 0,009, d = 1,58, Final: P = 0,02, d = 0,29).

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- 97
- 98 Conclusion

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100 Ces données indiquent que le plateau de VO<sub>2</sub> décrit dans les études historiques était très 101 probablement un artefact. Des recherches plus approfondies, évitant de se baser sur les 102 présupposés vraisemblablement erronés des études historiques, pourraient permettre 103 aux physiologistes de l'exercice et aux praticiens de déterminer quelle combinaison de 104 protocole d'exercice et de méthode d'acquisition de données est la plus propice à 105 l'induction et à la détection d'un authentique plateau de VO<sub>2</sub>.

- 107
- 108 Mots-clés: Exercice maximal; Consommation d'oxygène; Plateau;
- 109
- 110

#### **2.0 Introduction** 111

The concept and existence of maximal oxygen uptake (VO<sub>2max</sub>) remains a contemporary and 112 contentious topic of debate <sup>2-4</sup>. Central to this debate (and indeed concept of  $\dot{V}O_{2max}$ ) is  $\dot{V}O_2$ 113 plateau, it being the only objective criteria to indicate the attainment of  $\dot{V}O_{2max}$ . 114

Much debate has focussed on whether VO<sub>2max</sub> or plateau was achieved in historical studies. 115 The use of short discontinuous tests (DCT), as opposed to modern ramp tests, was used 116 commonly  $^{1,5,6}$  to investigate  $\dot{V}O_{2max}$ . Taylor, et al. <sup>1</sup> was the first study to detect  $\dot{V}O_2$  plateau 117 in a large number of participants and has been asserted as empirical evidence that  $\dot{V}O_2$  during 118 progressive exercise meets a limit that cannot be exceeded. Taylor, et al. <sup>1</sup> compared two DCT 119 protocols using a motorised treadmill to assess  $\dot{V}O_{2max}$ . The first of these tests used the Hill 120 model of incremental speed increases at a predetermined gradient  $(n=13)^{5,6}$ . The second 121 comprised incremented gradient increases (2.5%) at a constant speed (11.3 km.h<sup>-1</sup>) (n=115)<sup>5,6</sup>. 122

The advent of breath-by-breath analysis, providing greater insight into the time course of 123 oxygen uptake ( $\dot{V}O_2$  kinetics)<sup>7,8</sup>, raises questions as to whether apparent plateau in classical 124 studies was in fact artefactual, and indicative of measuring  $\dot{V}O_2$  in the non-steady (dynamic) 125 state <sup>2-4,9</sup>. However, debate has focussed on re-examination of published data from classic 126 studies <sup>5,6</sup>, rather than use breath-by-breath analyses to provide clear, empirical evidence. 127

In contemporary debate, the seminal works of A.V. Hill and colleagues <sup>5,6</sup> have been used to 128 evidence the existence, or otherwise, of VO<sub>2</sub> plateau <sup>2-4</sup>. However, this work is empirically 129 irreproducible due to the variable speeds and collection periods utilised <sup>5,6</sup>. However, the work 130 of Taylor, et al.<sup>1</sup>, who utilised motorised treadmills, fixed collection periods and reported 131 higher incidences of VO<sub>2</sub> plateau, would enable successful replication. Further, results obtained 132 through replicating Taylor, et al.<sup>1</sup> would be equally applicable to those of A. V. Hill and 133 colleagues, as it is likely  $\dot{V}O_2$  was still measured in the non-steady state. 134

In Taylor, et al.<sup>1</sup>, participants were required to run for 3 min; expired gas was then collected 135 136 between 1.75-2.75 min. This timing was rationalized with the explanation that mean  $\dot{V}O_2$  did not increase when gas was collected between 2 min 45 s and 3 min 45 s (3.48 L.min<sup>-1</sup> vs. 3.45 137 L.min<sup>-1</sup>). However, these values were not taken from the full sample. The treadmill gradient 138 was increased by increments of 2.5% on consecutive days until either a VO<sub>2</sub> plateau was 139 detected or the participant failed to complete 3 min. This makes Taylor, et al.<sup>1</sup> a suitable study 140 to replicate in order to investigate incidence of plateau in historical studies. 141

A clear answer as to whether  $\dot{V}O_2$  was artefactual in classic studies would enable contemporary 142 debate to move on. Therefore, the aims of the present study were (1) to investigate whether 143 early  $\dot{V}O_{2max}$  assessments underestimated actual  $\dot{V}O_2$ , and (2) to investigate whether the 144 apparent  $\dot{V}O_2$  plateau observed in classic studies was an artefact of measuring in a non-steady 145 146 state.

#### **3.0 Methods** 147

#### **3.1 Participants** 148

Twelve male recreationally active participants (mean  $\pm$  SD; age  $28 \pm 7$  y, height  $1.78 \pm 0.05$ 149 m, mass  $80 \pm 11$  kg) volunteered to participate in this study, which had been approved by the 150 151 institutional research ethics committee. Written and 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 h and 6 h, 153
- respectively. This study conformed to the Declaration of Helsinki. 154

#### 155 **3.2 Protocol**

- Participants visited one-of-two laboratories, with identical equipment, to perform a DCT on a 156 motorised treadmill (Ergo ELG 70, Woodway GmbH, Weil & Rhein, Germany), for the 157 determination of  $\dot{V}O_{2peak}$  and  $\dot{V}O_{2}$  plateau. The test started at 11.3 km.h<sup>-1</sup> and a 0% gradient, 158 and consisted of 8 min stages of running at increased gradient (2.5% increments) until 159 volitional exhaustion, with no more than two transitions performed in a 24-hour period. The 160 test was terminated when the participant was unable to perform a minimum of 3 min exercise 161 at a given stage. Participants were instructed to perform maximally and to maintain the exercise 162 for as long as possible. 163
- 164 During the DCT test, participants wore a nose clip and breathed through a low-dead-space (90 165 mL), low-resistance (5.5 cmH<sub>2</sub>O at 510 L.min<sup>-1</sup>) mouthpiece and impeller turbine transducer 166 assembly (Jaeger Triple V, Jaeger GmbH, Hoechburg, Germany). Inspired and expired gas 167 volume and concentration signals were continuously sampled (at 100 Hz) and drawn from the 168 mouthpiece through a 2-m sampling line (0.5 mm internal diameter) to paramagnetic (O<sub>2</sub>) and 169 infrared (CO<sub>2</sub>) analysers (Jaeger Oxycon Pro, Hoechburg, Germany).

#### 170 **3.3 Data Analyses**

- 171 The 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 <sup>10</sup>. Subsequently, the breath-by-breath data were interpolated to second-by-second
- 174 data and time aligned to the start of exercise.
- 175 The  $\dot{V}O_{2peak}$  was calculated as the highest 60-s sequential average.  $\dot{V}O_2$  was also determined
- between 1.75-2.75 min for comparison to the findings in the sample of Taylor, et al. <sup>1</sup>. Plateau
- was subsequently defined as a change in VO<sub>2</sub> of <150ml.min<sup>-1</sup> or <2.1ml.kg<sup>-1</sup>.min<sup>-1</sup> between
- 178 successive stages during the incremental stages <sup>1</sup>. Thus, an 80% confidence interval was 179 actually used to determine  $\dot{VO}_2$  plateau, according to Taylor's criteria <sup>1</sup>. Using this approach,
- a plateau in the  $\dot{V}O_2$  treadmill gradient relationship was evident and produced plateau in 69%
- of the participants using the continuous Hill approach and in 94% (108 of 115) of participants
- 182 using the discontinuous approach  $^{5,6}$ .

## 183 **3.4 Statistical analyses**

- 184 Linear regression was used to determine the slope of the  $\dot{VO}_2$  response and was determined for 1.75-2.75 min, and over the final minute of each DCT stage. A one-sample *t*-test was used to
- 186 compare the slope of the  $\dot{VO}_2$  response derived from the regression analysis. A paired-sample
- 187 *t*-test was used to compare  $\dot{V}O_{2peak}$  derived from the criteria of Taylor<sup>1</sup> and final collection.
- 188 Statistical significance was set as P < 0.05, and effect sizes were reported using Cohen's  $d^{11}$ .
- 189 Data were presented as mean  $\pm$  SD unless otherwise stated.

## 190 **4.0 Results**

- 191 The  $\dot{VO}_{2peak,Final}$  was found to be significantly higher than  $\dot{VO}_{2peak,Taylor}$  (Table 1.) (*P*<0.001, *d* 192 = 1.18). The slope of the  $\dot{VO}_2$  response, calculated from the last completed gradient for each 193 participant was significantly different from zero during the 1.75-2.75 min (Taylor: *P*=0.009, *d* 194 = 1.58; Final: *P*=0.02, *d* = 0.29). Incidence of a  $\dot{VO}_2$  plateau ( $\Delta \dot{VO}_2$  of <150ml min<sup>-1</sup> or 195 <2.1ml kg<sup>-1</sup> min<sup>-1</sup> between increments) was observed in 7 of 12 participants (58%), with some 196 demonstrating multiple instances of plateau. Each participant successfully completed an 197 additional increment and achieved higher  $\dot{VO}_2$  following observation of a plateau.
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200 **Table 1 about here**
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- 202 \*\*Figure 1 about here\*\*
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#### 204 5.0 Discussion

The principal findings of this investigation were that in classic studies <sup>1</sup>, measured  $\dot{VO}_{2peak}$ could not have been  $\dot{VO}_{2max}$ , and, apparent plateau was clearly artefactual.

Taylor, et al. <sup>1</sup> considered measurement of  $\dot{V}O_2$  beyond 3 minutes to have no perceivable benefit, and similarly short collection periods were utilised by Hill and colleagues <sup>5,6</sup>. The present study sought to demonstrate that when stage length was increased or higher intensities were attempted, a higher  $\dot{V}O_2$  would be shown and these data clearly demonstrate a higher  $\dot{V}O_2$ is achieved, if stages are extended. Highlighting the fact that short stages will be measuring  $\dot{V}O_2$  in the non-steady state, which is the cause of the artefactual plateau.

Taylor, et al. <sup>1</sup> was a pragmatic study to replicate due to the high variability in speed and collection periods reported in Hill and colleagues <sup>5,6</sup>, whilst Taylor, et al. <sup>1</sup> utilised motorised treadmills, uniform collection periods and reported high incidence of plateau. However, findings of the present study would be equally applicable to A. V. Hill and colleagues, as it is likely  $\dot{V}O_2$  was still measured in the non-steady state. The advent of breath-by-breath analyses has enabled far greater scrutiny of whether  $\dot{V}O_{2max}$  is achieved, thereby allowing demonstration of an artefactual  $\dot{V}O_2$  plateau.

This study has not sought to add to clarification of the existence, or otherwise, of  $\dot{V}O_2$  plateau 220 (and by definition, VO<sub>2max</sub>), and cannot comment on mechanistic action. This study has, 221 222 however, clearly demonstrated that  $\dot{V}O_2$  plateau in historical studies was artefactual <sup>1</sup>. It is evident that contemporary debate needs to move on, with little value in re-examination of, and 223 referral to this historical work. Further investigation without the fallacious assumptions of 224 225 historical studies may enable exercise physiologists and practitioners to determine which combination of exercise protocol and method of data acquisition is most conducive to elicit 226 and detect a  $\dot{V}O_2$  plateau. 227

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#### 281 7.0 Figure Captions

Figure 1. Individual participant plot for the same increment showing the measured  $\dot{V}O_2$ response to an exhaustive treadmill run. The individual slopes of  $\dot{V}O_{2.Taylor}(a)$  and  $\dot{V}O_{2.Final}(b)$ have been demarcated (bold lines), and for the last completed increment lasting approximately 3.5 min. This shows the measured  $\dot{V}O_2$  response to an exhaustive treadmill run and the slope of  $\Delta \dot{V}O_2$  during  $\dot{V}O_{2.Taylor}$  (c) and  $\dot{V}O_{2.Final}$  (d). 

# **8.0 Tables**

313	Table 1. Group	o data obtained	from the final	constant-speed	treadmill runs.
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Parameter	Taylor	Final			
$\dot{V}O_2 (ml^{-}min^{-1})$	$4109\pm310$	$4480\pm509^*$			
Slope (ml·min <sup>-2</sup> )	$231 \pm 146^{\#}$	$35\pm123^{\ddagger}$			
* Significantly different from <i>Taylor</i> ( <i>P</i> <0.001, $d = 1.18$ ). # Significantly different from 0 ( <i>P</i> =0.009, $d = 1.58$ ). *Significantly different from 0 ( <i>P</i> =0.02, $d = 0.29$ ).					



