Prior Knowledge of Trial Number Influences the Incidence of Plateau at VO2max

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Abstract
The purpose of this study was to assess the VO2max plateau response at VO2max during a series of pre-determined trials. METHODS: Ten male well-trained athletes (age, 23.0 ± 3.2; height, 183.3 ± 5.5 cm; mass 77.5 ± 11.1 Kg; VO2max 66.5 ± 5.0 ml kg-1 min-1), but who were VO2max testing naïve and with prior-knowledge of trial number completed four incremental tests to volitional exhaustion, separated by ~72-h for the determination of VO2max and gas exchange threshold. Throughout all trials VO2max was recorded on a breath-by-breath basis using a pre-calibrated metabolic cart, using a plateau criterion of ∆ VO2 ≤1.5 ml kg-1 min-1 over the final 2 consecutive 30 s sampling periods. A significant difference was observed between trial-1 and trial-4 for plateau incidence (p = 0.0285) rising from 20% in trial-1 to a 70% response rate in trial-4. Furthermore, a significant difference was observed for VO2max (difference between criterion value and ∆ VO2) in trial-1, 1.02 ± 1.69 ml kg-1 min-1 (p = 0.038), with non-significant differences observed for all other trials, despite a non-significant difference for VO2max across all trials (p > 0.05). Finally, a significant difference was observed for effort perception (RPE) at volitional exhaustion between trial-1 (17.7 ± 1.3) and trial-4 (19.0 ± 1.4) (p = 0.0052). These data indicate that prior-knowledge of trial number can influence the manifestation of the VO2 max plateau in a group of well-trained male athletes, thereby suggesting that a form of effort control is established in order to preserve the finite anaerobic capacity.

Key words: Maximal oxygen uptake; effort control; anaerobic capacity; experience.

Introduction
The classical outcome of a maximal oxygen uptake test (VO2max) is the manifestation of a plateau-like response in VO2 in spite of a continued increase in exercise intensity, the so called ‘true’ VO2max. First identified and defined by Hill and Lupton (1923) VO2max represents the uppermost boundary for aerobic metabolism and reflects the integrated response of the cardiovascular, respiratory and muscular systems to take-up and utilise oxygen. The conventional understanding for the generation of the plateau in VO2 towards the end of such a test, is that an imbalance ensues between the demand for oxygen at the engaged muscle, as expressed by the arterio-venous oxygen difference (a-VO2diff) and the ability of the cardiopulmonary system to supply oxygenated blood to the muscle to meet the imposed demand, which at sea-level is primarily limited by the cardiac output (Q). As volitional exhaustion approaches, both Q and a-VO2diff exhibit a plateauing response (Calbet et al., 2007) with VO2 as measured directly at the mouth, also levelling-out. Accordingly the plateau continues to be considered as the primary criteria in establishing VO2max (Hill and Lupton, 1923; Shephard et al., 1968). However there is an increasing body of evidence which suggests that there are significant variances in reported plateau incidence manifest as a function of athlete ability, ergometer selection, VO2 sampling rates and exercise protocol (Astorino, 2009; Doherty et al., 2003; Gordon et al., 2012).

A possible contributor to this variance in plateau incidence is the differential ability to recruit type II muscle fibres and hence regulate anaerobic substrate metabolism as recently proposed (Hawkings et al., 2007; Gordon et al., 2011). Thus it has been suggested that the levelling off in VO2 is dependent on the size of the finite anaerobic capacity, with a significant negative relationship being observed between the ∆VO2 during the final 60 s of the incremental test and the surrogate measure of anaerobic capacity, maximally accumulated oxygen deficit (MAOD) (Gordon et al., 2011). Further support for these conclusions has come from work showing that when the VO2max trial was preceded by a bout of prior-priming exercise, in the heavy or severe exercise domains, plateau incidence increased by 50 and 35%, respectively, from a baseline response rate of 50% in the un-primed state (Gordon et al., 2012). The proposed rationale for this response being that such prior-priming spares the finite anaerobic capacity at the onset of exercise by reducing the size of the O2 deficit.

During closed-loop exercise, such as time-trialling in cycling, it is generally accepted that the participant adopts a pacing strategy in order to optimise performance (Ansley et al., 2004; Foster et al., 2004; Hettinga et al., 2006). Pacing strategies have been attributed to maximising substrate metabolism whilst compensating for the consequences of fatigue (Noakes and St Clair Gibson, 2004; St Clair Gibson et al., 2006). Accordingly it is proposed that exercise intensity is modulated in response to afferent signals from biological and psychological systems, which relay the responses of the exercise challenge to the brain where appropriate effert, homeostatic-orientated responses are issued. The rationale for these
modulations in pace is to ensure that the finite anaerobic capacity never becomes fully depleted (Foster et al., 2004; Stone et al., 2012). A primary facet of this model is that regulation of effort is the product of an algorithm whereby an individuals’ conscious perception of effort (rating of perceived exertion, RPE) is continuously compared to a sub-conscious template which is, in turn derived from previous exposure to the sensations of pain and fatigue and the expectation of the exercise duration (Billaut et al., 2011; Tucker, 2011). In this connection, recent work by (Green et al., 2010) established that pacing is a product of training status with those individuals, who were more experienced and well-trained, showing a greater propensity for adopting a suitable effort-control response during a close-looped exercise than less experienced counterparts.

This situation contrasts with traditional VO$_2$max tests where the participant is unaware of the end-point thereby creating an open-looped condition. Open-looped exercise poses a potential conflict to the pacing model, as it has been suggested that in order to regulate pace and thereby effort, an endpoint is needed (Mauger and Sculthorpe, 2012). Given that the pacing/effort paradigm is based upon the establishment of a perceptual-based template, the contention is that such a template could be developed purely in response to the sensations of pain and fatigue established during initial experience of these conditions. Hence during a series of repeated trials there would be a regulation of force-output and substrate utilisation through anaerobic pathways in response to the previously established sub-conscious template (Stone et al., 2012). Thus the a-priori hypothesis was that in a group of VO$_2$max testing naive participants the incidence of plateau would increase across a series of trials and be highest in the final trial due to the development of the perceptual-based template derived from the need to conserve the finite anaerobic capacity in earlier trials. Accordingly the purpose of this study was to examine if prior knowledge of a VO$_2$max test influences the manifestation of the plateau at VO$_2$max in a series of subsequent incremental tests to volitional exhaustion in a group of well-trained individuals.

Methods

Participants
Following local institutional ethical approval (Anglia Ruskin University, UK) and having provided written and informed consent a total of 10 male trained cyclists volunteered to participate in the study (age, 23.0 ± 3.2 yrs; height, 1.83 ± 0.06 m; mass 77.5 ± 11.1 Kg). If any participant indicated a contraindication to exercise such as asthma, recent infection, or hypertension, they were excluded from the study. The criterion for classification of trained was a VO$_2$max ≥ 60 ml kg$^{-1}$ min$^{-1}$ and participation in aerobic endurance training > 3 times per week for > 3 years. An additional key inclusion criterion was imposed, that the participants had not undertaken any form of VO$_2$max testing prior to this study. Throughout the course of the study the participants were encouraged to maintain their normal daily and training routines, but to refrain from any physical activity in the 24-h period preceding any laboratory test. All participants were instructed to report to the laboratory fully hydrated and having consumed a balanced meal at least 3-h prior to the test.

Study design
Each participant reported to the laboratory on four separate occasions to undertake an incremental test to exhaustion, with all trials being at the same time of day so as to minimise diurnal variation, with each visit separated by at least 48-h, but no longer than 96-h. Four trials were selected as they would allow for an understanding of the effect of prior knowledge but would not have a large enough time frame between the first and last trial to be significantly affected by training and de-training responses. During each visit the participants completed an incremental test to exhaustion on an electronically controlled cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands) for the determination of VO$_2$max and gaseous exchange threshold (GET). The geometry of the cycle ergometer was established for each participant during the first trial and then maintained for all subsequent trials. The participants were not made aware of the primary rationale for the study and were simply informed that the focus of the research was on VO$_2$max repeatability.

**VO$_2$max protocol:** For the determination of both GET and VO$_2$max the participants undertook an incremental ramp test to volitional exhaustion, from an initial workload of 100 W for 1 min followed by a ramped increase in resistance of 0.42 W s$^{-1}$. For all trials the participants were asked to maintain a constant cadence of 80 rpm and the test was terminated when the cadence decreased by > 5 rpm from that prescribed, or when they reached volitional exhaustion. During each trial, pulmonary gas exchange variables (VO$_2$, VCO$_2$, VE and RER) were recorded on a breath-by-breath basis using a pre-calibrated metabolic cart (MSX 671; Ferraris Respiratory, Middlesex, UK). Heart rate responses were also recorded, continuously, throughout the course of all trials (Polar 810s, Kemple, Finland), with the data averaged on a 15 s basis. Additionally RPE was ascertained using the 6-20 scale and was collected both pre and immediately upon completion of the exercise challenge. For trial-1 the incremental test was preceded by a self-selected warm-up which was also monitored. To ensure consistency across the remaining trials (2-4) the initial warm-up was standardised for each individual using that adopted for trial-1. Throughout all of the trials verbal encouragement was regulated in accordance with previous work (Andreacci et al., 2002). No verbal encouragement was given until 6 min of the test had elapsed and here it was applied in the form of a chosen phrase such as “you’re doing well”. Similarly no further encouragement was given until an RER of 1.0 was observed when a reminder to the participant to maintain their selected cadence was provided. Finally no information was provided to the participant regarding their performance for trials 1-3, however upon completion of trial 4 they were given a full debrief as to what they had achieved.

For all trials a VO$_2$max was confirmed according to previously established methods (Doherty et al., 2003; Lucia et al., 2006) of a Δ VO$_2$ over the final 2 30 s sam-
sampling periods $\leq 1.5$ ml kg$^{-1}$ min$^{-1}$, which was designated as a plateau response. In the absence of a plateau, a maximal effort was established and a VO2peak confirmed according to previously established 'secondary' criteria: RER $\geq 1.15$, $\Delta$RER $\geq 0.4$, peak blood lactate (pBLa) $\geq 8.0$ mM, a RPE $>19$ (Gordon et al., 2012) and a maximal heart rate (HRmax) 205.8-0.685(age) $\pm$ 3 b min$^{-1}$ (Inbar et al., 1994). If neither the primary (plateau), nor secondary criteria were met, the test was deemed a non-maximal effort and discarded. Additionally GET was determined according to the excess CO2 method (ExCO2) (Volkov et al., 1975), where ExCO2 reflects an exercise intensity where the production of CO2 exceeds that witnessed under steady-state conditions and is expressed as $((\text{VCO2} / \text{VO2}) - \text{VCO2})$.

Prior to all trials commencing, baseline capillary blood samples were collected for the automated analysis of haemoglobin (5 μl) and haematocrit (10 μl) and erythrocytes (10 μl) (Dr LP20 Miniphotometer, Dr Lange, Germany). Additionally blood lactate samples were recorded both pre and immediately post exercise (10 μl) (GM7 Micro-Stat analyser, Analox Instruments, UK). All equipment was calibrated according to the manufacturers’ instructions.

**Pulmonary gas exchange variables:** During all of the incremental trials respiratory volumes and flow were determined with the participant breathing through a low resistance mouthpiece and turbine assembly. Expired gas concentrations (O2, CO2, N2 and Ar) were analysed continuously at a rate of 60 ml min$^{-1}$ via a fine-wire capillary line of 2 m and a bore of 0.5 mm connected to the mouthpiece assembly. Using custom metabolic cart software, respiratory volumes and gas concentrations were aligned and processed to obtain respiratory gas exchange variables (VO2, VCO2, VE, RER). Prior to each trial, the metabolic cart was calibrated in line with manufacturers’ specifications and in accordance with previous studies. In accordance with previous studies (Astorino and White 2010; Midgley et al., 2006) the coefficient of variation within our laboratory for athletes of a similar age and training status using the same protocol as adopted for this study is 3.4%.

**Statistical analysis**

The plateau in VO2 was calculated along with all of the aforementioned secondary data, means and standard deviations were derived for all variables. Using Levene’s test for homogeneity of variance the data was shown to be both normally distributed and homogenous. As this was the case a repeated measures ANOVA was applied to assess the null hypothesis that athlete experience has no influence on the indices of VO2max, GET and associated sub-maximal responses. To determine the presence, or absence, of a plateau the slope in VO2 during the final 60 s of the incremental test was determined using least squares regression. Confirmation of plateau manifestation was evaluated using a non-parametric binomial test, where $\Delta$ VO2 $\geq 1.5$ ml kg$^{-1}$ min$^{-1}$ =0 (no plateau) and $<1.5$ ml kg$^{-1}$ min$^{-1}$ =1 (plateau). A binomial test was also used to assess VO2dif = the difference between the derived $\Delta$VO2 and the prescribed $\Delta$VO2 criterion value for a plateau response of 1.5 ml kg$^{-1}$ min$^{-1}$, where Trial 1 > Trial 4 =1 and Trial 1 < Trial 4 =0.

Plateau incidence was also confirmed using a repeated measures ANOVA which was applied to the regression slope of the VO2 data to determine if there was any treatment x participant interaction. For the RPE data, a non-parametric Kruskal-Wallis ANOVA was applied. For all statistical analysis the alpha level was set at $p < 0.05$ and all analyses completed using SPSS version 20 (SPSS, Chicago, IL).

**Results**

Of the 10 participants only 2 met the primary criteria for a plateau in VO2 at VO2max ($<1.5$ ml kg$^{-1}$ min$^{-1}$) for trial-1. For trial-2 the response rate was 5 out of 10 which was also repeated for trial-3 while for trial-4 the response rate was 7 out of 10 participants. This indicates a significant difference between trials 1 and 4 ($p = 0.028$) and a trend towards increasing plateau attainment from trial-1 to -4. Although not showing a significant difference, the $\Delta$VO2 across the final 2 30 s sampling periods demonstrated a distinct negative trend of 1.23 ml kg$^{-1}$ min$^{-1}$ between trials-1 and -4. This trend is illustrated in Figure 1, where 9 out of 10 participants exhibited a VO2dif in trial-4 that was less than those in trial-1. Here a binomial test revealed a significant difference ($p = 0.02$) in VO2 between trials-1 and -4. Additionally when the $\Delta$ VO2 response during the final 60 s of the test was directly compared to the plateau criteria of 1.5 ml kg$^{-1}$ min$^{-1}$ (VO2dif) a significant difference was observed for trial-1, 1.02 $\pm$ 1.69 ($p = 0.04$), with non-significant differences revealed for trial-2, 0.17 $\pm$ 1.11, trial-3, 0.18 $\pm$1.24 and trial-4 of -0.22 $\pm$ 0.78 ml kg$^{-1}$ min$^{-1}$ ($p > 0.05$). Non-significant differences were observed for all other trial interactions ($p > 0.05$).

![Figure 1](image-url)
trial \((p > 0.05)\). The RPE’s recorded at the point of test termination across the four trials were \(17.7 \pm 1.3, 18.3 \pm 1.4, 18.7 \pm 1.1\) and \(19.0 \pm 1.4\) for trials -1 to -4 respectively. These data revealed a highly significant difference for effort perception between trial-1 and trial-4 \((p = 0.005)\). Additionally when considering the RPE within trials it was shown to be significantly, but negatively correlated against \(\Delta VO_2\) for trial-1, \(r = -0.658\) \((p = 0.04)\) and positively correlated for trial-4, \(r = 0.654\) \((p = 0.04)\.

The haematological responses obtained prior to trial-1 were \(144.3 \pm 13.8\) g.dl\(^{-1}\) (Hb), \(44.7 \pm 5.2\) % (HcT) and (Ery) \(4.81 \pm 0.56\) (mio.μl\(^{-1}\)), with no significant changes in any of these variables across the 4 trials \((p > 0.05)\). All performance and physiologically derived responses to the four incremental test trials are presented in Table 1, which shows that there were for the majority of indices no-significant differences across trial.

**Discussion**

The purpose of this study was to explore whether during a series of repeated, traditionally orientated \(VO_2\)max trials, a controlled-effort was employed. An *a-priori* hypothesis was established based on the prediction of pacing being employed as a response to the need to modulate substrate metabolism across trials, to ensure that the finite anaerobic capacity never becomes fully depleted (Foster et al., 2004; Tucker, 2011). Since the plateau in \(VO_2\) at \(VO_2\)max is a function of the same finite anaerobic capacity (Hawkins et al., 2007; Gordon et al., 2011), it was further hypothesised that plateau incidence would increase with repeated exercise trials. The reported findings support this hypothesis showing an increased incidence of plateau response between trial-1 and trial-4, coupled with a significant difference in \(\Delta VO_2\) between trial-1 and trial-4. These differences were manifest despite no other changes in measured responses, including exercise time to exhaustion, \(VO_2\)max or GET.

During an incremental test to exhaustion, using a similar protocol to that adopted for the current study, it has previously been demonstrated that there was a significant decrease in the finite high energy phosphate capacity (Green and Patla, 1992). Indeed Green et al., (1992) indicated that upon arrival at \(VO_2\)max and hence volitional exhaustion, the PCR concentration decreased by 86% in approximate proportion to the increase in free Pi. As a consequence of the increasing exercise intensity and associated decline in the PCR concentration, there was a notable decrease in the intramuscular glycogen concentration, coupled with an increase in muscle lactate and IMP, resulting in a significant decrease in muscle pH (Bertuzzi et al., 2013; Cooke et al., 1988; Green and Patla, 1992). Previous work suggests that effort-control strategies are adopted through a conscious and/or subconscious desire to limit the onset of premature fatigue through a modulation of work over the desired task duration (Billaut et al., 2011; Tucker 2011). By integrating this modulation of work to the metabolic changes associated with fatigue, (H+, pH, decreasing muscle glycogen, PCR etc.) skeletal muscle mass recruitment can be regulated to match mechanical output against performance (Billaut et al., 2011; Foster et al., 2004; St Clair Gibson et al., 2006). Such a strategy would be established at the onset of the exercise challenge, based upon previous associated sensations of pain and fatigue (Billaut et al., 2011; St Clair Gibson et al., 2006), current physiological (substrate availability, metabolic by-products etc.) and psychological state (motivation, arousal etc.), together with a perceptually

### Table 1. Physiological and performance derived responses across the four trials. Data are means (+SD).

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(VO_2)max (l.min(^{-1}))</td>
<td>4.98 (.55)</td>
<td>4.97 (.46)</td>
<td>4.94 (.47)</td>
<td>5.12 (.57)</td>
</tr>
<tr>
<td>(VO_2)max (ml.kg(^{-1}).min(^{-1}))</td>
<td>66.45 (5.02)</td>
<td>66.42 (5.09)</td>
<td>65.95 (5.03)</td>
<td>68.78 (7.05)</td>
</tr>
<tr>
<td>(\Delta VO_2) (ml.kg(^{-1}).min(^{-1}))</td>
<td>1.16 (1.94)</td>
<td>1.29 (1.75)</td>
<td>1.59 (1.27)</td>
<td>.86 (1.33)</td>
</tr>
<tr>
<td>(VCO_2)max (l.min(^{-1}))</td>
<td>5.32 (.52)</td>
<td>5.31 (.64)</td>
<td>5.43 (.41)</td>
<td>5.31 (.47)</td>
</tr>
<tr>
<td>(VCO_2)max (ml.kg(^{-1}).min(^{-1}))</td>
<td>71.16 (5.49)</td>
<td>70.70 (5.79)</td>
<td>72.69 (6.40)</td>
<td>71.42 (6.79)</td>
</tr>
<tr>
<td>(AVCO_2) (ml.kg(^{-1}).min(^{-1}))</td>
<td>2.27 (2.03)</td>
<td>2.46 (1.82)</td>
<td>2.87 (1.25)</td>
<td>1.72 (1.48)</td>
</tr>
<tr>
<td>RER(_{max})</td>
<td>1.08 (.07)</td>
<td>1.08 (.08)</td>
<td>1.11 (.06)</td>
<td>1.05 (.06)</td>
</tr>
<tr>
<td>(VE)max (l.min(^{-1}))</td>
<td>184.15 (17.22)</td>
<td>185.36 (18.74)</td>
<td>189.82 (20.52)</td>
<td>188.39 (22.81)</td>
</tr>
<tr>
<td>GET% (VO_2)max</td>
<td>59.36 (5.38)</td>
<td>59.38 (7.79)</td>
<td>59.73 (6.33)</td>
<td>59.36 (4.35)</td>
</tr>
<tr>
<td>HR(_{max})</td>
<td>184.2 (10.3)</td>
<td>183.1 (7.8)</td>
<td>181.5 (8.9)</td>
<td>183.5 (10.8)</td>
</tr>
<tr>
<td>(BLA)(_{max})</td>
<td>9.80 (2.30)</td>
<td>9.29 (2.75)</td>
<td>8.72 (1.49)</td>
<td>9.56 (2.61)</td>
</tr>
<tr>
<td>(W)(_{max})</td>
<td>422.75 (22.39)</td>
<td>425.63 (18.95)</td>
<td>421.85 (14.72)</td>
<td>426.05 (14.93)</td>
</tr>
</tbody>
</table>

Where \(\Delta VO_2\) = change in \(VO_2\) over the final two consecutive 30 s sampling periods, \(\Delta VCO_2\) = change in \(VCO_2\) during the final two consecutive 30 s sampling periods, RER\(_{max}\) = respiratory exchange ratio obtained at \(VO_2\)max , \(VE\)\(_{max}\) = minute ventilation at \(VO_2\)max, GET% \(VO_2\)max = gas exchange threshold expressed as a % \(VO_2\)max, HR\(_{max}\) = heart rate recorded at \(VO_2\)max , \(BLA\)\(_{max}\) = blood lactate concentration recorded at the point of volitional exhaustion, \(W\)\(_{max}\) = power output derived at volitional exhaustion.

### Table 2. Time orientated responses across the four trials. Data are means (+SD).

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (s)</td>
<td>834.6 (53.7)</td>
<td>841.5 (45.5)</td>
<td>832.4 (35.3)</td>
<td>842.5 (35.8)</td>
</tr>
<tr>
<td>(VO_2)max-arr (s)</td>
<td>813.6 (52.2)</td>
<td>817.5 (38.7)</td>
<td>814.4 (33.3)</td>
<td>818.5 (32.9)</td>
</tr>
<tr>
<td>(VO_2)max-Tlim (s)</td>
<td>21.0 (12.6)</td>
<td>24.0 (14.5)</td>
<td>21.0 (12.6)</td>
<td>24.0 (14.5)</td>
</tr>
<tr>
<td>GET (s)</td>
<td>479.0 (52.2)</td>
<td>484.9 (65.3)</td>
<td>485.2 (58.9)</td>
<td>481.8 (44.4)</td>
</tr>
<tr>
<td>GET – (VO_2)max(s)</td>
<td>337.2 (51.0)</td>
<td>332.6 (71.3)</td>
<td>326.3 (49.7)</td>
<td>341.5 (34.1)</td>
</tr>
</tbody>
</table>

Where Total = total exercise time from trial onset to volitional exhaustion, \(VO_2\)max-arr = time taken from exercise onset to the onset of \(VO_2\)max, \(VO_2\)max-Tlim = time from \(VO_2\)max arrival to volitional exhaustion, GET = time taken from exercise onset to the gas exchange threshold and GET – \(VO_2\)max = time taken from gas exchange threshold to the point of volitional exhaustion.

However, in the present study the participants were VO2max testing naïve so for trial-1 had no previously established perceptual template against which to modulate their effort, but were fully aware of the total study duration (4-trials). Accordingly for the initial exercise challenge (trial-1), participants had no perception of the end-point against which work could be modulated, hence rendering the feedback from the engaged muscles redundant in this context. In this connection it is interesting that trial-1 exercise time was, on average, 8 s shorter than that of trial-4 (longest), supporting the contention that for trial-4 there was a perceptual template against which work could be modulated.

Of course the participants in the present study were not totally naïve to the nature of the protocol employed as they were both well-trained and aware of the total number of trials which they needed to perform. The latter factor is significant to an effort-control paradigm, which projects that an exercise end-point is a fundamental component to the perceptual template in regards to the allocation of both physiological and psychological assets (Billaut et al. 2011; St Clair Gibson et al., 2006). The paradigm based upon the notion of effort modulation which is a function of previously established homeostatic or reference sensations (Damasio et al., 2000; 2001), which becomes a permanent set-point against which all subsequent exposures to the same activity are compared. The contention being that where the exposure is not immediate the perceptual regulation of effort ensues.

When an exercise end-point is not known (number of trials) there is a down regulation of muscle activity in order to reduce the metabolic cost and thereby spare the finite anaerobic capacity (Billaut et al., 2011). It is contended that the plateau variance, observed in the present study, is a function of the prior knowledge of the number of trials to be completed, so a maximal effort could be applied in the final (fourth) trial. Trial-1 (two) and -3 both showed an identical but increased (50%) plateau incidence and by association a greater reliance on the finite anaerobic capacity (Billaut et al., 2011). It is consequent to reduce the metabolic cost and thereby spare the finite anaerobic capacity during incremental testing. Here, despite a reduction in blood volume of ~450 mm³ and associated decrease in O₂ carrying capacity of ~9%, there was no change in plateau incidence, suggesting that during an incremental test to exhaustion the finite anaerobic capacity is still not fully depleted. So although in the present study the participants could not modulate mechanical force output the data would suggest that they adopted a metabolically orientated control of effort, in response to prior knowledge of both trial number and exposure to the sensations of pain and fatigue.

The training status of the participants in the study is also of importance to the outcomes observed. Previous work, (Green et al., 2010) highlights that pacing is a function of training volume and experience. All the cyclists in the present study were well-trained endurance athletes, (VO2max: 66.5 ± 5.0 mlkg⁻¹min⁻¹ and training history of >3 years). Hence whilst the detailed training history of the participants was not known, it is accepted that in order to enhance endurance capability the athlete would need to undertake both low intensity and interval-based training (Billat, 2001; Seiler et al., 2006). Since the latter would typically be in excess of the GET the athlete would be subject to the sensations of pain and fatigue, similar to those experienced during an incremental exercise test.

In a recent study Scharhag-Rosenberger et al., (2014) demonstrated that with just 1.5-h recovery between VO2max trials, four incremental tests could be completed with no-significant effect on either VO2max or Wmax. This was in a group of trained endurance athletes, displaying similar physical characteristics to those completing the present study. The lack of change in VO2max reported by Scharhag-Rosenberger et al. (2014) is in agreement with that shown in the present study. These findings along with others (Hawkins et al., 2007; Wagner, 2000) suggest that although VO2max is primarily limited by cardiac output and O₂ extraction/utilisation at the muscle, the plateau is independent of these responses. Indeed recent works (Calbet et al., 2007) suggest that Qmax is attained at ~86% Wmax as a function of a levelling off in stroke volume (SV) at ~64% Wmax. These findings suggest that the maintenance of force generation in response to the continual increase in exercise intensity is a consequence of the reliance on the finite reserves of the high energy phosphates and intramuscular glycogen. Although the relevance of the VO2max plateau in establishing a maximal effort has been challenged (Alpert, 1992; Noakes, 2008) its significance should not be under-estimated. For as Hill and Lupton, (1923) first projected the existence of the plateau is central to the notion of a maximal rate of oxygen uptake and conforms to the concept of VO2max being dependent on Qmax. Of note is that in this population group of VO2max naïve participants the plateau response rate was lower than reported values in the literature for athletes of equitable fitness (Astorino 2009; Doherty et al., 2003; Gordon et al., 2011). Given that the VO2 plateau is considered the primary criterion in determination of a maximal effort these findings lend support to the need for such approaches as a verification trial, particularly when the participant is naïve to the exercise challenge. Accordingly debate continues as to the variance in plateau incidence with potential contributors being ergometer type (Gordon et al., 2012), protocol (Kon-Yoon et al., 2007), sampling and analysis methods (Astorino, 2009; Robers et al., 2010) and population group (Doherty et al., 2003; Lucia et al., 2006). However in order for the debate to be framed and the generation of a series of industry recognised guidelines there needs to be recognition of what the plateau is and represents.

**Conclusion**

This study has demonstrated that in a group of well-
trained male endurance cyclists, a closed-loop condition is established with prior knowledge of trial number which triggers the sparring of the finite anaerobic capacity when exposed to the sensations of pain and fatigue which are evident during such trials. It is proposed that by establishing the closed-loop condition prior to commencement of data collection that a metabolically orientated control of effort ensues which prevents both a depletion of the anaerobic energy reserves and resultant prolonged exposure to the sensations of pain and fatigue. Future work should address whether plateau manifestation shows a similar response pattern in both un-trained individuals who have not had significant exposure to the sensations of exercise-induced pain and fatigue, or in female participants as the majority of research to date focuses on responses in male participants.

References


Key points
- In well-trained athletes the incidence of plateau at VO2max increases in conjunction with an increase in trial number and the associated sensations of pain and fatigue.
- By informing the participant of the number of trials to be completed a closed-loop condition is developed whereby effort in all trials is compared to a perceptually developed template.
- Closed-loop condition leads to a sparing of the finite anaerobic capacity during incremental tests when the number of trials to be completed is known.

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