

ORIGINAL ARTICLE

Elucidating determinants of the plateau in oxygen consumption at $\dot{V}O_{2MAX}$

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Background: A plateau in oxygen consumption ($\dot{V}O_2$) is the primary means of confirming that maximal oxygen uptake ($\dot{V}O_{2MAX}$) is attained during incremental exercise to fatigue. However, it is still unresolved what causes expression of a plateau in $\dot{V}O_2$ at the end of incremental exercise.

Objectives: To elucidate incidence and identify determinants of the $\dot{V}O_2$ plateau in subjects of varying fitness.

Methods: Thirty subjects (mean (SD) age and $\dot{V}O_{2MAX}$ 26.9 (9.8) years and 3.4 (0.8) litre/min respectively) were separated into three groups: endurance trained (ET; n = 9), recreationally active (Rec; n = 11), and strength/sprint trained (STR; n = 10). During three separate visits, subjects completed incremental treadmill exercise during which breath by breath gas exchange data were obtained. Body composition was measured using a three site skinfolds model. Force production of the knee extensors and flexors was assessed using isokinetic dynamometry.

Results: $\dot{V}O_{2MAX}$ was significantly higher ($p < 0.05$) in the ET group vs STR and Rec. The change in $\dot{V}O_2$ ($\Delta\dot{V}O_2$) at $\dot{V}O_{2MAX}$ was not different ($p > 0.05$) in the ET group (33.0 (27.3) ml/min) compared with the Rec group (30.3 (24.1) ml/min) and the STR group (44.4 (23.8) ml/min). No correlations ($p > 0.05$) were evident between $\Delta\dot{V}O_2$ at $\dot{V}O_{2MAX}$ and $\dot{V}O_{2MAX}$ ($r = 0.05$), fat-free mass ($r = 0.12$), and muscular strength ($r = -0.12$).

Conclusions: The incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$ (from correlation data) is not due to factors related to training status or physical fitness of subjects, but is altered by analysis and interpretation of gas exchange data.

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In healthy people, maximal oxygen consumption ($\dot{V}O_{2MAX}$), the maximal rate of oxygen consumption by active muscle during exercise to fatigue, is an index of endurance performance as well as a measure of maximal cardiopulmonary function. In the laboratory setting, $\dot{V}O_{2MAX}$ is commonly measured during incremental exercise to fatigue on a treadmill or cycle ergometer, during which expired air is analysed by gas analysers. Despite the fact that the $\dot{V}O_{2MAX}$ concept has existed for over 80 years, there are no standardised guidelines to confirm incidence of $\dot{V}O_{2MAX}$. The most widely used criterion for confirming attainment of $\dot{V}O_{2MAX}$ is a levelling off (plateau) in oxygen consumption at $\dot{V}O_{2MAX}$, yet the magnitude of this plateau used varies among scientists. Classic work¹ developed the most widely accepted $\dot{V}O_2$ plateau (change in $\dot{V}O_2$ ($\Delta\dot{V}O_2$) at $\dot{V}O_{2MAX} \leq 150$ ml/min) from multiday, discontinuous exercise testing in 115 healthy men. Later work² suggested a $\Delta\dot{V}O_2 \leq 80$ ml/min, whereas other work³ in six men described a plateau in $\dot{V}O_2$ as no significant change in the slope of $\dot{V}O_2$ versus time. Data from our laboratory⁴ in 16 subjects completing maximal cycle ergometry revealed 100% incidence of a plateau in $\dot{V}O_2$ when a more stringent plateau criterion ($\Delta\dot{V}O_2 \leq 50$ ml/min at $\dot{V}O_{2MAX}$) was used. Consequently, it is evident that no single $\Delta\dot{V}O_2$ exists to confirm incidence of $\dot{V}O_{2MAX}$. It is therefore recommendable to examine this $\dot{V}O_2$ plateau phenomenon in a large, more diverse population of subjects after repeated $\dot{V}O_{2MAX}$ tests.

Previous work⁵ suggests that the incidence of the $\dot{V}O_2$ plateau is lower in the unfit, elderly, and the young. Research in equally trained men and boys⁶ showed low incidence (23.8% and 12.5% respectively) of a plateau in $\dot{V}O_2$ (final $\Delta\dot{V}O_2$ less than 50% of the average $\Delta\dot{V}O_2$ per stage) in response to incremental treadmill testing, similar to data (29% incidence) from Paterson *et al*⁷ in 10–12 year old boys.

However, in elderly men and women giving a “good effort,” a plateau in $\dot{V}O_2$ ($\Delta\dot{V}O_2 \leq 2.0$ ml/kg/min) was evident in 55–78.9% of subjects.⁸ Similarly, data⁴ in young, recreationally active subjects completing maximal cycle ergometry reported the universal incidence of a plateau in $\dot{V}O_2$ when stringent plateau criteria were used. Data showed that the sampling interval dramatically affects the prevalence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$. For example, the incidence of a plateau in $\dot{V}O_2$ was 100% when data were obtained using shorter sampling intervals (breath by breath and 15 seconds), yet the incidence was lower (57% and 8% respectively) with longer (30 and 60 seconds) sampling intervals. These results suggest that it is the sampling interval and not subject status that explains the dissimilar incidence of a plateau in $\dot{V}O_2$ across various studies. Moreover, the incidence of this plateau phenomenon varies across studies because of different protocols, subjects, and plateau criteria used. This indicates that a priori measurement issues selected by the researcher may determine the presence or absence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$. It is also unclear if a plateau in $\dot{V}O_2$ exists in subjects unfamiliar with graded exercise testing.

Previous work⁵ supporting one minute sampling intervals as the optimal duration for acquiring gas exchange data suggests that subjects may have to maintain maximal to supramaximal work rates for two to three minutes at the end of a test to achieve a plateau in $\dot{V}O_2$. This is physiologically impractical and unlikely, especially in non-athletes, children, and the elderly. However, it does intimate that factors including $\dot{V}O_{2MAX}$, fat-free mass (FFM), and muscular strength may determine the incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$. At the end of a $\dot{V}O_{2MAX}$ test, there is a greater

Abbreviations: FFM, fat-free mass; $\dot{V}O_{2MAX}$, maximal oxygen consumption

contribution of non-oxidative pathways to ATP provision, hence greater muscle mass and force production may allow a subject to tolerate the ever increasing ATP demand, exercise longer, and perhaps reveal a higher incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$.

The primary aim of this investigation was to examine the incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$ in subjects from a variety of exercise backgrounds, and to identify determinants of this plateau by correlating measures of body composition, cardiovascular fitness, and muscular strength with $\Delta\dot{V}O_2$ at $\dot{V}O_{2MAX}$. A secondary aim was to discern if repeated $\dot{V}O_{2MAX}$ testing increases the incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$ by a testing effect.

MATERIALS AND METHODS

Subjects

Thirty healthy, active men and women (mean (SD) age 26.9 (9.8) years) were recruited from the university community. During their initial visit to the Human Performance Laboratory, subjects provided written informed consent and

filled out a health/history questionnaire to confirm that they were free from any conditions that prevented them from fulfilling any requirements of the study. Subjects were separated into three groups: an endurance trained group (ET; $n = 9$) consisting of competitive triathletes, cyclists, and runners; a recreationally active group (Rec; $n = 11$) active in athletics and regular cardiovascular/weight training exercise, and a strength/sprint trained group (STR; $n = 10$) comprising sprinters and people participating in heavy resistance training four to six days a week with minimal (≤ 30 minutes a week) cardiovascular exercise.

Assessment of body composition

Body height and mass were measured with the subjects dressed in shorts and T shirt. Body composition was assessed using skinfold callipers (Lange Beta Technology, Cambridge, Maryland, USA). The primary investigator measured subcutaneous fat at three sites on the body (chest, abdomen, and thigh for men, and triceps, thigh, and anterior suprailiac for women) following standardised procedures.⁹ Sum of

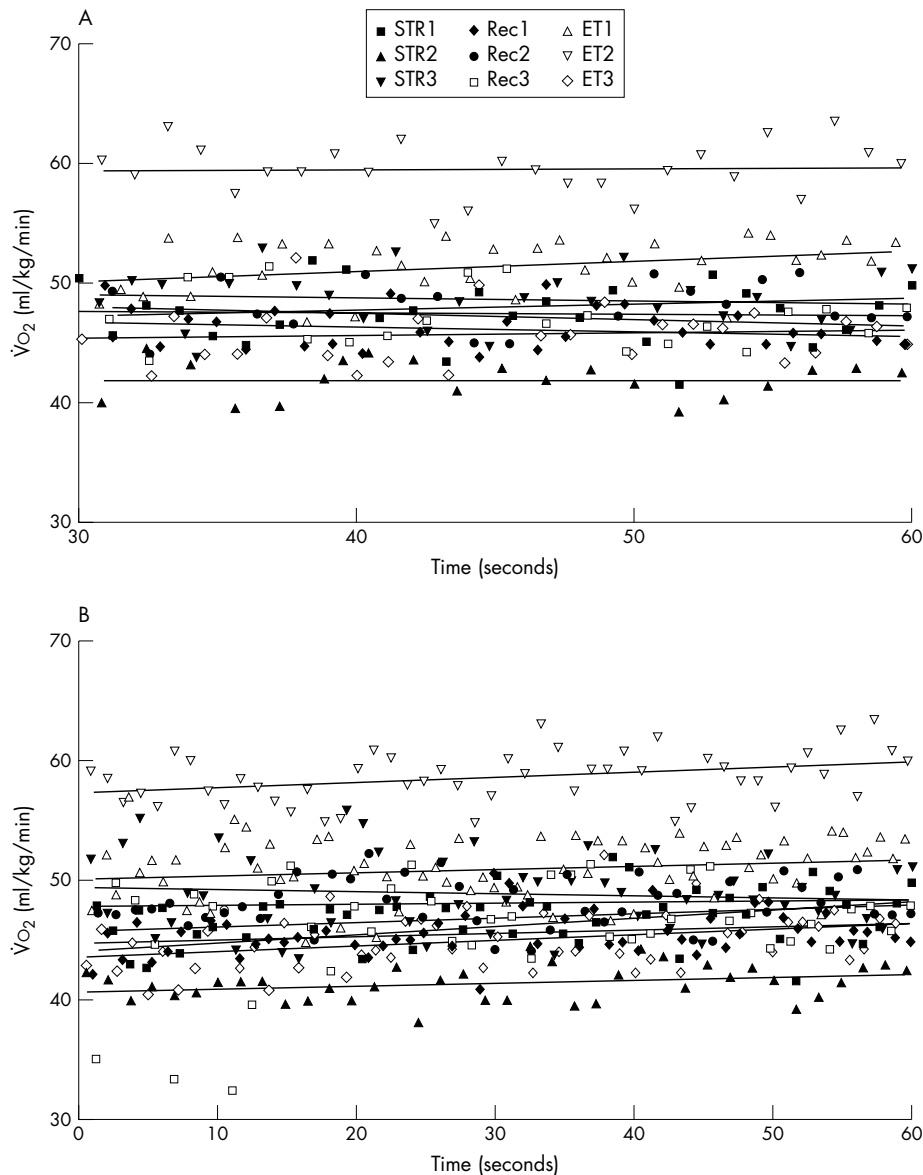


Figure 1 Regression lines describing the change in $\dot{V}O_2$ versus time during the last 30 seconds (A) and 60 seconds (B) of incremental exercise for three subjects in the endurance trained (ET), recreationally active (Rec), and strength/sprint trained (STR) groups.

skinfolds was converted into percentage body fat (%BF) using a common nomogram.¹⁰ FFM was calculated by subtracting fat mass from body mass. Two measurements at each site were taken in rotational order, and a third measurement was recorded if the first two measures deviated by more than 10%.

$\dot{V}O_{2\max}$ testing

Initially, subjects completed a familiarisation test of $\dot{V}O_{2\max}$ on a treadmill (Quinton Instruments Q55, Series 90, Seattle, Washington, USA). During testing, expired breath was measured using infrared gas analysers, and heart rate was recorded continuously throughout exercise (Polar Electro Inc, Woodbury, New York, USA). During $\dot{V}O_{2\max}$ testing, subjects expired through a plastic mouthpiece and low resistance valve into tubing connected to a mixing chamber. Measurements of ventilation, $\dot{V}O_2$, and carbon dioxide production were obtained breath by breath throughout exercise by a metabolic cart (SensorMedics Model 29C, Yorba Linda, California, USA). Throughout the test, treadmill speed remained constant at a speed selected by the subject, and grade was increased at a rate of 0.5–1.0% each minute until fatigue. $\dot{V}O_{2\max}$ was confirmed by the following criteria: (a) a plateau in $\dot{V}O_2$ ($\Delta\dot{V}O_2 \leq 50$ ml/min); (b) respiratory exchange ratio greater than 1.10.⁴ Test duration was 8–14 minutes.¹¹ $\dot{V}O_{2\max}$ (l/min) was defined as the workload attained when the subject requested to stop exercising, and represented the mean of $\dot{V}O_{2\text{PEAK}}$ and the closest neighbouring data point at volitional fatigue. During exercise, rating of perceived exertion¹² was obtained, and the subject was given verbal encouragement to exercise to volitional fatigue. Subjects were given no feedback during testing.

At the same time of day during the next two visits (separated by at least 48 hours), subjects repeated the $\dot{V}O_{2\max}$ test on the treadmill. Treadmill speed and grade increment were identical to the initial test. Before each visit, the subject refrained from consumption of alcohol and caffeine for 48 hours and strenuous exercise for 12 hours. Subjects were required to maintain a normal dietary and exercise regimen during participation in the study, which was confirmed with 24 hour food and exercise logs.

Assessment of muscular force

On a separate occasion, muscular force of the knee extensors and flexors was determined using an isokinetic machine (BioDex System 2, Shirley, New York, USA). This required concentric maximal flexion and extension of the knee of the dominant leg at various contraction velocities (60, 90, 120, 180, 225, and 300°/s). Before testing, subjects warmed up on a cycle ergometer for five minutes, and stretched the knee extensors and flexors. They were then instructed to exert maximal effort during all repetitions. A short rest period (45 seconds) was allotted between each repetition. Maximal force (torque), work, and relative force (N/m/kg FFM) were obtained for both extension and flexion.

Statistical analysis

Data are reported as mean (SD) and were analysed using GraphPad Prism version 3.0 (San Diego, California, USA). One way analysis of variance with repeated measures was used to examine differences in gas exchange variables between the three $\dot{V}O_{2\max}$ tests. One way analysis of variance was used to locate differences in $\dot{V}O_{2\max}$, %BF, and muscular force between groups. If a significant *F* ratio was obtained, Tukey's post hoc test was used to identify differences between means. Pearson's correlation coefficient and stepwise regression were used to identify relationship between $\Delta\dot{V}O_2$ at $\dot{V}O_{2\max}$ and FFM, $\dot{V}O_{2\max}$, and muscular force. Linear regression was used to determine the slope of the $\dot{V}O_2$

versus time relationship at the end of incremental exercise. With a sample size equal to 10, and mean $\dot{V}O_{2\max}$ equal to 3.45 (0.73) l/min, statistical power was 0.13. Statistical significance was set at 0.05.

RESULTS

$\dot{V}O_{2\max}$ testing

Mean $\dot{V}O_{2\max}$ was not significantly different ($p = 0.07$) from trial 1 (3.5 (0.7) l/min) to trial 2 (3.6 (0.8) l/min) and trial 3 (3.5 (0.7) l/min) in our 30 subjects. $\dot{V}O_{2\max}$ was significantly higher ($p < 0.05$) in the ET group (52.1 (4.3) ml/kg/min) than the Rec (45.9 (3.8) ml/kg/min) and STR (45.7 (3.2) ml/kg/min) groups. Mean $\Delta\dot{V}O_2$ at $\dot{V}O_{2\max}$ was similar ($p > 0.05$) in the ET (33.0 (27.3) ml/min), Rec (30.3 (24.1) ml/min), and STR (44.4 (23.8) ml/min) groups. Using the criterion of $\Delta\dot{V}O_2 \leq 50$ ml/min at $\dot{V}O_{2\max}$, a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\max}$ was found in a majority of subjects in the ET (66%), Rec (82%), and STR (60%) groups. Figure 1A shows regression lines of the $\dot{V}O_2$ versus time relationship for three subjects in each group during the last 30 seconds of incremental treadmill exercise. In these subjects, $\dot{V}O_{2\max}$ was 40–60 ml/kg/min. All slopes of $\dot{V}O_2$ versus time were not significantly different from zero, indicating attainment of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\max}$ for all subjects. However, when the last 60 seconds of gas exchange data were analysed (fig 1B), the slopes for four subjects were significantly different from zero; therefore the $\dot{V}O_2$ plateau occurred in only five of nine subjects. For example, the slopes for subjects ET2 and STR1 were significantly different from zero ($p < 0.05$): 0.043 (0.016) and 0.037 (0.023) ml/kg/min/s respectively.

Assessment of body composition

Mean %BF was lower ($p < 0.05$) in STR compared to ET and Rec. Percent body fat (mean \pm SD) was equal to 11.0 (4.0), 15.0 (5.1), and 17.7 (5.8)% in STR, ET, and Rec, respectively.

Assessment of muscular force

Relative muscular force of the knee extensors was equal to 3.4 (0.6), 2.9 (0.6), and 3.0 (0.8) N.m/kg FFM respectively in the STR, ET, and Rec groups. Knee extensor force did not differ ($p = 0.19$) among the groups. Similarly, the maximal force of the knee flexors was comparable ($p = 0.16$) among the groups: STR (1.8 (0.3) N.m/kg FFM), ET (1.6 (0.2) N.m/kg FFM), and Rec (1.6 (0.3) N.m/kg FFM).

Correlation and regression analyses

A significant positive relationship ($r = 0.81$, $p < 0.05$) was exhibited between maximal force of the knee extensors and FFM. However, no significant relationship ($p > 0.05$) was evident between $\Delta\dot{V}O_2$ at $\dot{V}O_{2\max}$ and FFM, maximal force of the knee extensors and knee flexors, and $\dot{V}O_{2\max}$ (fig 2A–D).

Three-predictor regression models were developed to ascertain significant predictors of $\Delta\dot{V}O_2$ at $\dot{V}O_{2\max}$. Only three predictors were used to maintain a case to variable ratio of at least 10:1.¹³ A model including age, FFM, and knee flexor yielded the largest R^2 value (0.213), with age ($p = 0.018$) as the only significant predictor of $\Delta\dot{V}O_2$. Age by itself accounted for 16% of the variance in $\Delta\dot{V}O_2$ at $\dot{V}O_{2\max}$. A model comprising maximal gas exchange and cardiovascular data (heart rate, $\dot{V}O_{2\max}$, and respiratory exchange ratio) yielded an R^2 value of 0.007.

DISCUSSION

The primary aim of this study was to elucidate incidence, and identify determinants of, the plateau in $\dot{V}O_2$ at $\dot{V}O_{2\max}$ in subjects participating in endurance, power, and recreationally based activities. Subjects completed multiple $\dot{V}O_{2\max}$ tests and a separate test of muscular strength using isokinetic

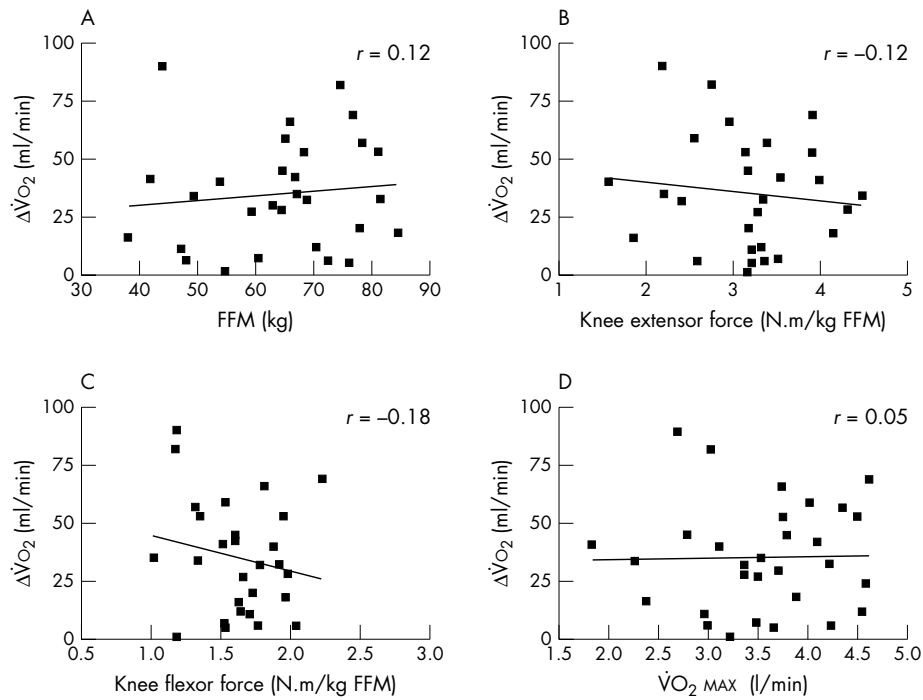


Figure 2 Relationship between $\Delta\dot{V}O_2$ and (A) fat-free mass (FFM), (B) knee extensor force, (C) knee flexor force, and (D) $\dot{V}O_{2MAX}$ in 30 subjects.

dynamometry. The results show a high incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$, illustrated by a mean $\Delta\dot{V}O_2$ at $\dot{V}O_{2MAX} \leq 50$ ml/min as well as incidence of slopes of $\dot{V}O_2$ versus time not different from zero in the later stages of incremental exercise. The only significant predictor of the $\Delta\dot{V}O_2$ at $\dot{V}O_{2MAX}$ was age, suggesting that body composition, training status, and/or training history do not affect incidence of the $\dot{V}O_2$ plateau. It

is suggested that sampling interval is the primary factor determining incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$ in most subjects exercising to volitional fatigue. Sampling interval and $\Delta\dot{V}O_2$ at $\dot{V}O_{2MAX}$ must be carefully selected by researchers to increase incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$, and the slope of $\dot{V}O_2$ versus time should also be used as an objective criterion to ascertain attainment of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2MAX}$.

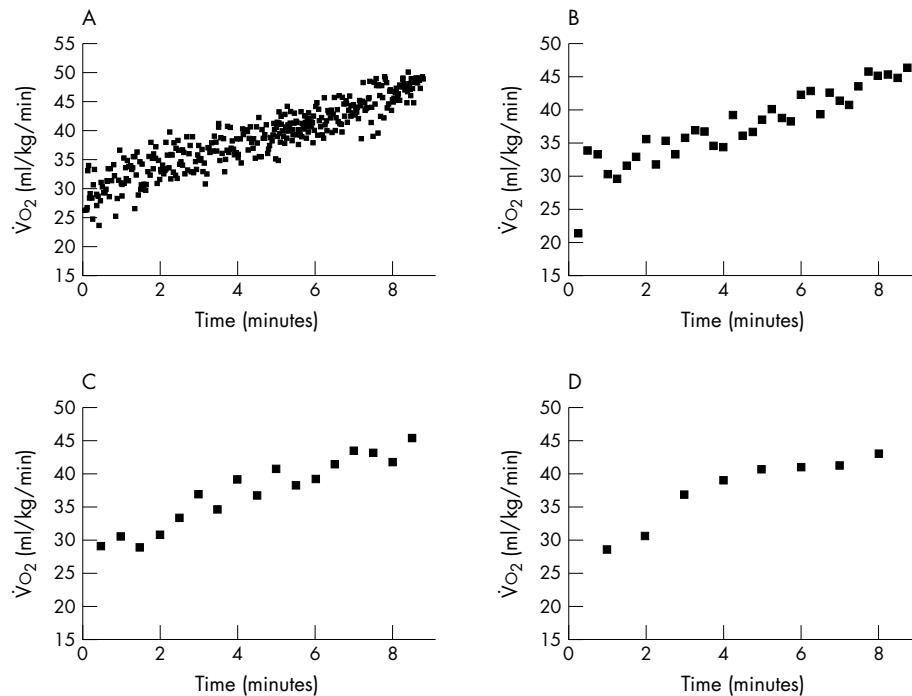


Figure 3 Alterations in $\dot{V}O_2$ plateau incidence with changes in sampling interval in response to maximal cycle ergometry in a recreationally active man.⁴ (A) Breath by breath; (B) every 15 seconds; (C) every 30 seconds; (D) every 60 seconds.

Our moderate to high incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ is dissimilar to recent data in young, healthy subjects. Research in 50 elite endurance athletes completing maximal treadmill exercise found a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ in only 39% of men and 25% of women.¹⁴ However, $\dot{V}O_{2\text{MAX}}$ was represented as the highest $\dot{V}O_2$ attained for 60 seconds, and their plateau criterion was rather large (2.1 ml/kg/min). In 21 physically active men,⁶ a plateau in $\dot{V}O_2$ (final $\dot{V}O_2 \leq 50\%$ of the average change in $\dot{V}O_2$ per elevation stage during testing) occurred only 23.8% of the time. Data from Myers *et al*³ revealed a plateau in $\dot{V}O_2$ in only two of six subjects when gas exchange data were obtained breath by breath, yet these data are characterised by dramatic variability. In contrast, work from our laboratory¹⁵ in 37 active men and women revealed 87% and 76% incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ with shorter sampling intervals (breath by breath and 15 seconds), and lower incidence when gas exchange data were obtained every 30 seconds (57%) and 60 seconds (11%). In 20 men and women,¹⁶ a plateau in $\dot{V}O_2$ was observed in 80% of subjects during maximal cycle ergometry in which biomechanical signal processing techniques were used to identify incidence of the $\dot{V}O_2$ plateau. Consequently, it is plausible that different sampling intervals and magnitude of the plateau criterion used may explain these disparate findings regarding $\dot{V}O_2$ plateau incidence.

It is not known if multiple, identical $\dot{V}O_{2\text{MAX}}$ tests completed by a single subject increase the incidence of the $\dot{V}O_2$ plateau at $\dot{V}O_{2\text{MAX}}$. Previous data in five men¹⁷ completing up to three maximal treadmill tests a day showed a lower plateau incidence when incremental exercise was preceded by two earlier maximal trials. In our study, there was greater variability in the mean $\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ in trial 1 (38.8 (47.6) ml/min) than in subsequent trials (34.4 (22.6) ml/min and 35.8 (25.4) ml/min). However, all mean values were within our plateau criterion ($\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}} \leq 50$ ml/min). Furthermore, a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ was found in 80%, 80%, and 70% of subjects in trials 1 and 2 versus 3. These results indicate that completion of multiple bouts of incremental exercise on separate days does not affect the magnitude or incidence of the $\dot{V}O_2$ plateau at $\dot{V}O_{2\text{MAX}}$. Similarly, there was a high incidence of maximal respiratory exchange ratio (≥ 1.10 ; 77%, 80%, and 83%) and heart rate criteria (within 10 beats/min of 220 – age; 70%, 77%, and 64%) across trials, similar to recent data in 50 elite athletes.¹⁴ Overall, our subjects of varying fitness backgrounds were able to attain $\dot{V}O_{2\text{MAX}}$, and our data emphasise that a $\dot{V}O_2$ plateau is a real phenomenon in most subjects exercising to volitional fatigue.

So, what experimental conditions maximise incidence of the plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$? Exercise mode is not a factor, as a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ has been shown in response to incremental treadmill, cycle ergometer,^{15 16} and rowing exercise.¹⁸ Data from Duncan *et al*¹⁹ revealed that plateau incidence is similar with continuous (50%) and discontinuous (60%) protocols. However, researchers must seriously consider the exact sampling interval and magnitude of

What is already known on this topic

A plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ is recognised as a criterion to confirm attainment of $\dot{V}O_{2\text{MAX}}$. For years, researchers have used the criterion of $\Delta\dot{V}O_2 \leq 150$ ml/min at exercise termination to confirm $\dot{V}O_{2\text{MAX}}$ attainment, despite the fact that it was developed from discontinuous treadmill testing. In the 1990s, the research that developed the $\dot{V}O_{2\text{MAX}}$ concept, the fundamental measure of exercise physiology, was rightfully criticised, and yet the debate has ebbed.

What this study adds

This study elucidates physiological and methodological factors that may alter the incidence of the $\dot{V}O_2$ plateau at $\dot{V}O_{2\text{MAX}}$. The data show that a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ is a real phenomenon, and its occurrence is primarily a methodological issue. Objective and accurate measurement techniques that will increase plateau incidence are recommended. These data may modify current practice of using the obsolete criterion to confirm $\dot{V}O_{2\text{MAX}}$, and encourage the use of more objective and accurate plateau criteria. At worst, they may spur energetic debate of a very fundamental issue in exercise physiology.

plateau criterion to reveal high incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$. It appears that shorter sampling intervals (breath by breath and 15 seconds) increase the incidence of the plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ compared with the traditionally accepted 60 second interval. This is demonstrated in fig 3, gas exchange data from incremental cycle ergometry in an active male. It shows plateau incidence ($\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}} \leq 50$ ml/min) when gas exchange data are obtained breath by breath or every 15 seconds, yet no plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ with sampling intervals of 30 or 60 seconds.⁴ Longer sampling intervals also induce greater variability in $\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ and significantly reduce $\dot{V}O_{2\text{MAX}}$.¹⁵ The widespread availability of modern breath by breath gas exchange systems enables acquisition of gas exchange data with the greatest precision and temporal resolution. Through its ability to acquire data at shorter sampling intervals, this technology may increase the incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ irrespective of the type of exerciser, protocol, or mode of exercise. This technology also allows the researcher to select more stringent plateau criteria ($\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}} \leq 50$ ml/min) rather than traditionally accepted values ($\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}} \leq 150$ ml/min) obtained with Douglas bags.¹

CONCLUSIONS

Data demonstrated that $\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ was similar across ET, Rec, and STR athletes. Approximately 80% of fit, young subjects demonstrated a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ for all trials, and when the slope of $\dot{V}O_2$ versus time was analysed in nine subjects, all subjects revealed a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ with shorter sampling intervals. Multiple regression analysis identified age as the only significant predictor of $\Delta\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$, emphasising that muscular strength, FFM, and $\dot{V}O_{2\text{MAX}}$ do not alter incidence of the $\dot{V}O_2$ plateau. The exact magnitude of the $\dot{V}O_2$ plateau criterion selected as well as frequency of data sampling are better determinants of the plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ than subject factors. It is recommended that scientists acquire breath by breath gas exchange data, analyse the slope of $\dot{V}O_2$ versus time in the later stages of incremental exercise, and select a more stringent plateau criterion to maximise plateau attainment and obtain a more precise pattern of the $\dot{V}O_2$ response to incremental exercise. Incidence of a plateau in $\dot{V}O_2$ at $\dot{V}O_{2\text{MAX}}$ may be a primarily methodological, and not physiological, issue.

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COMMENTARY

For much of the past 50 years, exercise scientists and clinicians have assessed both baseline cardiorespiratory performance and the changes induced by aerobic training in terms of an individual’s maximal oxygen intake ($\dot{V}O_{2\text{MAX}}$).

Methods of determining $\dot{V}O_{2\text{MAX}}$ have been evaluated extensively by a number of well respected physiologists,^{1–3} and an international working party sponsored by the International Biological Programme subsequently standardized the test protocol.⁴ Testing in this era was based on the use of multiple Douglas bags, with the subject making maximal efforts on each of several days. None of these early investigators found difficulty in bringing most subjects (whether young or old) to a plateau of oxygen consumption as defined by Taylor and associates.¹ Nevertheless, it is fair to comment that subjects were pushed to extreme exhaustion, and some more recent researchers may have been reluctant to stress their subjects as severely. Wagner⁵ has argued that a “high pain and fatigue tolerance” is needed to develop an oxygen consumption plateau. The low prevalence of plateaus in athletes who were preparing themselves for Olympic competition⁶ does not negate Wagner’s view. In my experience, international competitors are often reluctant to make a supreme effort merely for the delight of a laboratory scientist. In support of my contention, some of the subjects tested by Doherty *et al*⁶ had a peak respiratory gas exchange ratio of less than 0.90—hardly a strong anaerobic effort! A further issue raised by this paper is the impact of breath by breath analysis on the demonstration of an oxygen consumption plateau. If a plateau is seen when using data from the last 15 seconds of two successive exercise stages, but disappears if data are averaged over the last 30 or 60 seconds, it may be that the current generation of subjects are reluctant to maintain peak effort as long as 60 seconds.

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