The VO_{2\text{max}} plateau is not associated with the anaerobic capacity in physically active subjects

Abstract

The present study aimed to verify if the incidence of plateau is associated with anaerobic capacity. Therefore, nine physically active male (age: 23 ± 4 yr; body mass: 72.4 ± 8.2 kg; height: 176.4 ± 6.8 cm; VO_{2\text{max}}: 41.3 ± 5.7 ml.kg^{-1}.min^{-1}) participated in the present study. The subjects in a cycle ergometer the following tests: a) maximum incremental test to determination of VO_{2\text{max}}; b) six submaximal tests for determination of supra maximum demand of O_2; c) supra maximum test for maximum accumulated oxygen deficit (MAOD) determination. The plateau was identified when the difference in the VO_{2} in the last two stages of incremental test was ≤ 2.1 ml.kg^{-1}.min^{-1}. It was observed an inverse correlation, although no significant, between MAOD and VO_{2} plateau (r = -0.61; p > 0.05). Thus, it appears that anaerobic capacity is not a decisive factor for determining the incidence of VO_{2} plateau in physically active individuals.

KEY WORDS: MAOD; Oxygen deficit; Stabilization of oxygen uptake; Incremental test; Supra maximum test.

Introduction

Traditionally, maximum oxygen consumption (VO_{2\text{max}}) has been used to represent the maximum aerobic capacity. Presently, VO_{2\text{max}} is used as an indicator of cardiorespiratory fitness, running performance predictor, to evaluate training related adaptations in healthy individuals and in patients with coronary arterial disease, detraining mortality predictor and to evaluate sleeping disorder. Thereby, VO_{2\text{max}} identification is important to evaluate the fitness levels in athletes as well as in high-risk groups. VO_{2\text{max}} is measured via incremental tests (TI), usually performed to voluntary exhaustion. Although several variables have been considered in order to establish maximum effort, the main characterization of VO_{2\text{max}} is through stabilization in oxygen consumption (VO_{2}) during the final stages of TI. This VO_{2} characterization during the final stages of TI has been termed VO_{2} plateau. Theoretically, plateau refers to a stabilization or small increases (≤ 2.1 ml.kg^{-1}.min^{-1}) of VO_{2}, even if loads are incremented in the final stages of TI. However, some tests are interrupted before reaching VO_{2\text{max}}. In this case, the value obtained is termed as peak oxygen consumption (VO_{2}\text{peak})\textsuperscript{15}. It has been suggested that plateau incidence may be related to athlete’s training state, in which athletes with higher physical condition could tolerate higher levels of pain and fatigue and higher motivation to support higher loads in the final test\textsuperscript{16-17}, and that the higher intensities could be related to increases in energy supply by the anaerobic metabolism\textsuperscript{1}.

Provided the relevance to establish VO_{2\text{max}} parameters, previous studies used one additional test to confirm if VO_{2} value, obtained in a traditional TI protocol, could be considered as maximum\textsuperscript{18-19}. The confirmation test is performed until fatigue with constant loads and intensities near to the VO_{2\text{max}}. For instance, Snell et al.\textsuperscript{19} performed the confirmation test with two intensities (95% and 105% of the maximum power in TI) and, in both conditions, it were not observed significant differences between VO_{2} in the verification test and the VO_{2}\text{max} achieved in TI, even in the absence...
of plateau. This result suggest that the maximum aerobic power can be achieved during TI, even if there is no plateau in VO2.

Previous studies with trained individuals have suggested that VO2 plateau may be related to the anaerobic metabolism\(^1\). During high-intensities exercises, the ATP resynthesis occurs predominantly via anaerobic metabolism, which seems to justify, in the final stages of the incremental test, an increase in exercise intensity even with no modifications VO2 (stabilization). In a recent study, Gordon et al.\(^1\) showed a negative correlation between ∆VO2 and maximum accumulated oxygen deficit (MAOD) in highly trained cyclists. These results indicate that individuals with higher anaerobic capacity have higher incidence of plateau. Given that MAOD is elevated in both aerobic and anaerobic trained individuals as compared with physical active ones\(^20\), it seems plausible to suggest a lower incidence of VO2 plateau in physical active and non-athletes individuals. However, to the present moment no study analyzed the relationship between anaerobic capacity and the VO2 plateau in individuals with low levels of physical condition.

Thus, the present study aimed to verify the relationship between anaerobic capacity measured via MAOD and the incidence of VO2 plateau in physical activity individuals. The hypothesis was that there would be positive correlations between MAOD and VO2 plateau.

### Method

#### Subjects

Nine male subjects participated in the present study 23 ± 4 years, 72.4 ± 8.2 kg e 176.4 ± 6.8 cm). They were physically active, healthy and had previous experience with exhaustion exercise. All participated in recreational sports and activities (running, soccer and tennis), however, none were engaged in competitive activities. All subjects were informed about the aims, procedures and possible risks associated with the present study and gave their informed consent prior to enrolment in the study. All subjects were free from pharmacological treatments, neuromuscular or cardiovascular disease and were non-smokers. The present study was approved by the commit of ethical research of the School of Physical Education and Sport of the University of Sao Paulo.

#### Experimental design

All subjects were submitted to four experimental sessions, with at least 72 h of interval between sessions. In the first session, subjects performed an incremental test to voluntary exhaustion in a cycle ergometer to measure VO2 max and its respective VO2 max power (WVO2 max). In the following sessions (i.e., second and third) subjects were submitted to six tests with constant loads (3 tests per session) with intensities below VO2 max. Sessions as well as sub-VO2 max tests order was randomized between subjects. Tests were performed in a controlled environment with constant room temperature (20-24 °C) and with two hours of interval from the last meal. Subjects were instructed not to performed strenuous physical exercises and not to consume alcohol 48 hours before data collection. In order to avoid any possible effect of ergogenic\(^21\) and circadian cycle\(^22\), all tests were performed in the same period of the day and subjects were instructed to not consume caffeine 48 hours before tests.

#### Anthropometric measures

Body mass and height were measured via an electronic scale (Filizola, model ID 1500, São Paulo, Brazil) and a wood stadiometer, respectively.

#### Incremental test

Incremental test was performed in an electromagnetic cycle ergometer for lower limbs (Godart-Holland, Lannoy). Immediately before test, subjects remained seated on the cycle ergometer for five minutes to determine baseline VO2 (VO2 LB). The VO2 LB refers to rest VO2, which was determined from the arithmetic mean of VO2 during the final 30 seconds of the rest. Three minutes after warm-up, with the inertial resistance from the equipment, subjects cycled with a cadence of 60 rpm and increments of intensity of 30 W.min\(^{-1}\). Test was interrupted when cadence was lower than 50 rpm. Throughout test, exchange gas and heart rate (HR) were measured breath-by-breath and beat-by-beat, respectively. VO2 was measured continuously via a portable gas analyzer (K4b2...
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The cycle ergometer, saddle height, pedal pace, warm-up, interruption criterion and VO\textsubscript{2} measurement in the exercises with constants loads were the same as in the progressive test until exhaustion. Subjects exercised for ten minutes, or until voluntary exhaustion, in six tests with intensities below the WVO\textsubscript{2}max: 40, 50, 60, 70, 80 and 90\% of WVO\textsubscript{2}max and one above WVO\textsubscript{2}max (110 WVO\textsubscript{2}max). The rest interval between tests was approximately ten minutes, or until subjects return to VO\textsubscript{2}LB values. Mean VO\textsubscript{2} values during the last minute of the test was used to represent the VO\textsubscript{2} in these tests.

The VO\textsubscript{2} DEM = \[(\text{b}*\text{110/60})*\text{t}\]

Where VO\textsubscript{2} DEM is the estimated O\textsubscript{2} demand during supra-WVO\textsubscript{2}max exercise; 110 is the intensity of the supra-WVO\textsubscript{2}max exercise; b is the angular coefficient in 1.min\textsuperscript{-1} obtained from the linear regression in the VO\textsubscript{2}-intensities in the sub-WVO\textsubscript{2}max tests; t is the total duration time of exercise expressed in seconds.

**Statistical analyses**

All analyses were performed with the SPSS software (version 13.0, Chicago, USA). Data normality was verified by Shapiro-Wilk test and all presented normal distribution. Data are reported as means and standard deviation (SD). The correlation coefficient between ∆VO\textsubscript{2} and MAOD was determined with Pearson linear correlation. VO\textsubscript{2}max and the 90\% VO\textsubscript{2} of the WVO\textsubscript{2}max values were compared by a paired T test. The unpaired T test was used for between-group comparisons (plateau vs. non-plateau) for all the dependent variables (VO\textsubscript{2}max, MAOD, peak power, peak heart rate, respiratory exchange ratio [R], peak blood lactate concentration, VO\textsubscript{2} at the ventilatory threshold and \% of ventilatory threshold of VO\textsubscript{2} related to VO\textsubscript{2} peak). The level of significance adopted was 5\% (p < 0.05).

**Results**

Variables related to the progressive test are presented in TABLE 1. It was not observed significant differences between VO\textsubscript{2}max and VO\textsubscript{2}peak obtained at 90\% of WVO\textsubscript{2}max (p > 0.05). The between-group comparisons revealed no significant differences for the dependent variables: maximum oxygen consumption (VO\textsubscript{2}max), peak power, peak heart rate, respiratory exchange ratio, peak blood lactate concentration, VO\textsubscript{2} at the ventilatory threshold and \% of the VO\textsubscript{2} of the ventilatory threshold in respect to VO\textsubscript{2}max (TABLE 2).
TABLE 2 - Between-group comparisons (plateau vs. non-plateau) for the progressive test variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Grupo platô</th>
<th>Grupo sem platô</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂max (l.min⁻¹)</td>
<td>3.0 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>VO₂max (ml.kg⁻¹.min⁻¹)</td>
<td>41.3 ± 5.7</td>
<td></td>
</tr>
<tr>
<td>Respiratory Exchange ratio (R)</td>
<td>1.29 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>Maximum power (Watts)</td>
<td>247 ± 39</td>
<td></td>
</tr>
<tr>
<td>Total duration time (min)</td>
<td>8 ± 1</td>
<td></td>
</tr>
<tr>
<td>Maximum heart rate (bpm)</td>
<td>180 ± 9</td>
<td></td>
</tr>
<tr>
<td>[La⁻] peak (mmol.l⁻¹)</td>
<td>10.3 ± 1.4</td>
<td></td>
</tr>
</tbody>
</table>

Five out of nine subjects presented VO₂ plateau (55% of the subjects). The correlation analysis in these subjects (FIGURE 1, left panel) showed a non-significant inverse correlation between ΔVO₂ and MAOD (r = -0.61, p = 0.270). Similar non-significant result was observed when pooling data from all subjects (r = 0.28; p = 0.464).

FIGURE 1 - Coefficient correlation between rate of increase in oxygen consumption (ΔVO₂) and maximum accumulated oxygen deficit (MAOD).
Discussion

The aim of the present study was to verify the relationship between anaerobic capacity and VO\textsubscript{2} plateau incidence in physically active subjects. Our hypothesis was that MAOD would be positively associated with VO\textsubscript{2} plateau. However, the results from the present study showed that VO\textsubscript{2} plateau incidence does not seem to be associated with the anaerobic capacity in physically active subjects.

The VO\textsubscript{2}\textsubscript{max} has been utilized to assess the maximum aerobic power\textsuperscript{1-2}. The presence of plateau is considered a key criterion to determine if the value obtained during the test can be considered as maximum\textsuperscript{19}. However, not all subjects are capable to achieve plateau state. Previous studies demonstrated a high heterogeneity of plateau incidence between 12 to 59\%\textsuperscript{1, 18, 23-26}. Studies in highly trained athletes showed similar or even lower percentage of plateau incidence as in the present study. Lucia et al.\textsuperscript{19} reported a plateau incidence of 47\% in elite professional cyclists, whereas Doherty\textsuperscript{23} showed a plateau incidence of 25\% and 39\% for men and women, respectively in Olympic athletes runners of medium and long distance. In the present study, five out of nine subjects presented plateau. These results are similar to Gordon et al.\textsuperscript{1} that observed plateau presence in four out of nine (44.4\%) highly training cyclists.

In the present study, we observed a non-significant correlation between MAOD and ΔVO\textsubscript{2}, which do not corroborate with the above-mentioned study\textsuperscript{3}, given that it was observed a significant negative correlation between variables (\(r = -0.77, p = 0.008\)) in highly trained cyclists that presented plateau (VO\textsubscript{2}max = 59.3 ± 4.8 ml.kg\(^{-1}.min\(^{-1}\)). This result suggest that, in physically active subjects, others variables seems to affect the plateau incidence, in addition to the anaerobic capacity. It has been suggested that the plateau incidence is associated with the individual capacity to support high levels of fatigue and its resistance to pain\textsuperscript{16}. However, highly trained athletes, which are familiarized with high levels of effort and pain sensation during training session and/or competitions, did not show higher incidence of plateau\textsuperscript{21, 25}, strengthening the idea of other intervening variables. Petit et al.\textsuperscript{17} have suggested that the incapacity to reach plateau in incremental test is due to the incapacity to support the high power levels demanded during the test final stages. In their study, an incremental test was performed to verify the VO\textsubscript{2}max. For the subjects that presented plateau or for those that the secondary criterion was achieved, even in the absence of plateau, a new test was performed. Test started similarly to the incremental test, with increases in load in a time function. When subjects achieved its VO\textsubscript{2}max, determined in the first test, the power was reduced until the subject was able to maintain the VO\textsubscript{2} values previously determined. Using this protocol, 100\% of subjects were able to reach plateau. Another study that corroborate with the present results is the Rivera-Brown et al.\textsuperscript{21} where the incidence of plateau in pre-pubertal boys was 33\% and, it was not observed any relationship between anaerobic power and plateau incidence. This results seems reinforce that other variables may be relevant to plateau incidence, as children's shown lower anaerobic capacity levels, thus, it would be expected a reduced incidence of plateau.

Additionally, results from the present study demonstrated that VO\textsubscript{2} peak at 90\% of WVO\textsubscript{2}max was not significant different from VO\textsubscript{2}max. That is, the VO\textsubscript{2} values obtained during the final TI can be considered as maximum, even for those subjects that did not reach plateau. Indeed, exercise performed within this level of effort (~90\% of WVO\textsubscript{2}max) usually achieve the VO\textsubscript{2}max values\textsuperscript{27}. Furthermore, peak heart rate, R and blood lactate concentrations reached elevated values, confirming that the values observed can be considered as maximum for all subjects\textsuperscript{2}. It was also demonstrated that individuals with higher levels of maximum aerobic power did not present a higher incidence of plateau. Altogether, these results suggests that when physically active subjects reach the first load correspondent to VO\textsubscript{2}max they interrupt the exercise.

Importantly, the present study has some limitations. First, only nine subjects were evaluated, which could have been insufficient to observe significant correlations between variables. Especially in the sub-analysis, in which it was considered only the subjects that presented plateau (\(n = 5\)). In this analysis we observed a negative correlation, however, it was not statistical significant. In order to observe significant correlations with small sample sizes it is necessary values nears of one (+1 or -1), which increase the chance for type II error (observe non-significant correlations between variables, when in fact there is significant correlations)\textsuperscript{28}. Limitations related to the use of MAOD to determine the anaerobic capacity should be highlighted, an impossibility to directly measure the variable, due to a lack of gold-standard method to determine the anaerobic

Rev Bras Educ Fís Esporte, (São Paulo) 2016 Out-Dez; 30(4):865-71 • 869
capacity; the use of VO$_2$ max to estimate the energetic metabolism that is measured as the whole-body, not being possible to account for the demand imposed by the musculoskeletal system during the exercise task; the contribution of the anaerobic lactic system on intensities above the anaerobic threshold are not excluded of the calculations and the slow component of VO$_2$ during the higher intensities may overestimate the O$_2$ demand. Despite these limitations, the MAOD has been considered as a decent method to estimate the anaerobic capacity.$^{6,29,30}$

In short, it was observed non-significant correlations between plateau and anaerobic capacity, suggesting that the plateau incidence it is not related only with the anaerobic capacity in physically active subjects. Altogether, these results indicate that for subjects with this level of training, the anaerobic capacity it is not the main predominant factor to plateau incidence.

Resumo

O platô do VO$_2$ max está associado à capacidade anaeróbia em indivíduos fisicamente ativos

O presente estudo teve como objetivo verificar se a incidência do platô está relacionada com a capacidade anaeróbia. Para tanto, nove indivíduos fisicamente ativos (idade: 23 ± 4 anos; massa corporal: 72,4 ± 8,2 kg; estatura: 176,4 ± 6,8 cm; VO$_2$ max: 41,3 ± 5,7 ml.kg$^{-1}$.min$^{-1}$) participaram do presente estudo. Eles foram submetidos aos seguintes testes, realizados em cicloergômetro: a) um teste incremental máximo para a determinação do VO$_2$ max; b) seis testes submáximos para determinar a demanda supramáxima de O$_2$; c) um teste supramáximo para a determinação do déficit máximo acumulado de oxigênio (MAOD). O platô foi caracterizado quando a diferença do VO$_2$ entre os dois últimos estágios do teste incremental foi ≤ 2,1 ml.kg$^{-1}$.min$^{-1}$. Foi observada uma correlação inversa, porém não significante, entre o MAOD e o platô do VO$_2$ (r = -0,61; p > 0,05). Dessa forma, parece que a capacidade anaeróbia não é fator decisivo para determinar a incidência de platô no VO$_2$ em indivíduos fisicamente ativos.

PALAVRAS-CHAVE: MAOD; Estabilização do consumo de oxigênio; Déficit de oxigênio; Teste incremental; Teste supramáximo.

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