OXYGEN UPTAKE PLATEAU OCCURRENCE IN TRAINED MALE AND FEMALE ADULTS

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Abstract. The attainment of an oxygen uptake ($\dot{V}O_2$) plateau during maximal incremental exercise is often considered as a criterion for the elicitation of a maximal effort. However there is growing evidence that a ($\dot{V}O_2$) plateau does not occur in all adult subjects despite exercise to volitional exhaustion. One school of thought is that aerobically trained subjects or subjects with a higher maximal $\dot{V}O_2$ were more likely to demonstrate the $\dot{V}O_2$ plateau phenomenon than subjects with lower maximal $\dot{V}O_2$. The study investigated the frequency of occurrence of the $\dot{V}O_2$ plateau, defined as an increase in $\dot{V}O_2$ of less than 1.5 ml/kg/min in trained Asian male (n=158, age=21.7±4.9y; body mass=64.8±8.6kg) and female (n=28, age=21.9±7.0y; body mass=53.0±7.0kg) athletes during a maximal treadmill run to volitional exhaustion, to determine maximal $\dot{V}O_2$. The $\dot{V}O_2$ plateau phenomenon was only detected in 53% of the male athletes and 64% of the female athletes, despite the lower ratio-scaled peak $\dot{V}O_2$ values (48.4±7.2 vs. 58.0±6.9 ml/kg BM/min; $p<0.05$) of the female athletes compared to the male athletes. These data refuted the assertions that athletes with higher aerobic fitness were more likely to show a $\dot{V}O_2$ plateau, and that the lack of a $\dot{V}O_2$ plateau was due to poor motivation on the part of untrained adults to give a maximal effort.

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Introduction

The attainment of a “plateau” or leveling off in oxygen consumption ($\dot{V}O_2$ plateau) despite increases in exercise intensity during an incremental test to volitional exhaustion remains a popular criterion for maximal effort [3]. Indeed some journal reviewers will not accept that a maximal effort during an incremental exercise test was elicited in the absence of an oxygen uptake plateau with increasing exercise intensity. It is argued that beyond the “plateau” in oxygen uptake, the additional energy provision to the exercise must come from anaerobic metabolism [3,9], albeit it should be acknowledged that there is always some energy contribution from anaerobic metabolism during an incremental exercise test. This is evidenced by the progressive increase in exercise blood lactate concentration over the exercise stages of the maximal oxygen uptake test [4].

Work using continuous exercise protocols to volitional exhaustion and online breath-by breath expired air analyses in both adolescents [10] and adults [5] have shown that an oxygen plateau occurs in 0-33% of the population tested [6]. In the majority of the studies, the samples tested were physically healthy and active people rather than trained athletes, and there is less work on trained athletes. To explain the plateau phenomenon, some researchers have suggested that only very fit athletes were able to attain an oxygen uptake plateau since arterial oxygen desaturation is more likely to occur in very fit athletes [11]. Indeed, he postulated that a $\dot{V}O_2$ plateau is likely to occur in human subjects with a high pain and fatigue tolerance and that in subjects whose pain or fatigue tolerance is low, the leg pain or exhaustion causes them to terminate the exercise with no evident $\dot{V}O_2$ plateau [11]. Nonetheless, this hypothesis has apparently not been evaluated using larger groups of trained athletes. Hence the primary purpose of the study was to examine the occurrence of the plateau phenomenon in oxygen uptake during an incremental treadmill exercise test in a large group of national-level athletes in Singapore.

Researchers have shown that in the absence of an oxygen uptake plateau during a maximal incremental test to volitional exhaustion, despite the fulfillment of other objectives (e.g. RER value of above 1.10 and a final exercise heart rate that is above 95% of the age-predicted maximum i.e. 220-age (yrs) [1] and subjective indications (e.g. facial flushing and unsteady gait) [2] of a maximal effort, the term peak $\dot{V}O_2$ or $\dot{V}O_2$ peak [2] is preferred to the term $\dot{V}O_{2\,max}$, which is synonymous to the occurrence of a $\dot{V}O_2$ plateau. The term, peak $\dot{V}O_2$ will be used in the present study to describe the attainment of maximal $\dot{V}O_2$, irrespective a whether a $\dot{V}O_2$ plateau is detected or not.

Materials and Methods

Subjects: One hundred fifty-eight males and 28 females were tested in the study. These subjects were considered as competitive athletes representing the country in different sports (e.g. soccer, hockey, runners, etc). The data were collected from athletes who have visited the exercise physiology laboratory of the Sports Medicine and Research Centre over the last decade. The benefits and risks of the tests were communicated to all the athletes and all signed a written informed consent prior to testing. For athletes who were tested several times during the period, the test in which his or her highest maximal oxygen uptake value was recorded and was subsequently used in the analysis.

Anthropometric measurements: The anthropometric measurements were made using calibrated scales. For stature, a Holtain stadiometer was used and for body mass a weighing scale (Seca, Hamburg, Germany) was used prior to the tests.

Treadmill test: The maximal $\dot{V}O_2$ test for the athletes was conducted using a continuous and an incremental protocol on a treadmill (Marquette 1900, Milwaukee, WI), following familarisation with treadmill running. Athletes were given a standardized warm-up consisting of two minutes at a walking pace followed a systematic trial and error method to determine a manageable running speed for the initiating the test. The athletes were instructed that the running speed should be one that they could endure for 12-15 min. Once chosen, the athlete ran at this speed for at least two minutes to allow steady-state to be achieved. This was followed by 10 minutes of stretching exercises for the lower limbs before the commencement of the treadmill test. All athletes were instructed to give a maximal effort and were verbally encouraged to run till volitional exhaustion was achieved.

The test commenced with a treadmill velocity that was between 8.0 and 14 $km \cdot h^{-1}$ with a zero percent grade for the first two minutes. Then for the next five minutes, treadmill elevation was increased by 2% at the end of each minute. Subsequently, the elevation was increased by 1% every minute until the subject achieved volitional exhaustion. Respiratory variables for oxygen uptake ($\dot{V}O_2$) and carbon dioxide ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER) were recorded every 20 s using an open-circuit spirometry system (Sensormedics 2900Z, Yorba Linda, CA). The oxygen and carbon dioxide gas analyzers were calibrated prior to each test with known concentrations of standard gases and the flowmeter was calibrated using a 3-litre syringe. Heart rate data were monitored throughout the test by means of short-range radio telemetry (Sport-tester, Polar Electro Oy, Finland).

Criteria for determination of maximal $\dot{V}O_2$ *effort:* All respiratory variables at maximal $\dot{V}O_2$ were reported as the highest 60 s (i.e. highest of three 20-second consecutive readings). The subject's maximal $\dot{V}O_2$ was achieved when two of the criteria were achieved: i) RER >1.05, ii) HR at test termination of >95% of age-predicted HR_{max} (based on 220 minus age in years) and (iii) exercising to volitional exhaustion.

Criterion for the attainment of a maximal $\dot{V}O_2$ *plateau:* The criterion that was used to determine the attainment of a $\dot{V}O_2$ plateau was a $\dot{V}O_2$ increase of less than 1.5 ml/kg/min [5,8].

Statistical analyses: All data were analysed using SPSS Windows (version 11.5). Descriptive statistics (mean ±SD) were generated for anthropometric characteristics of the participants (i.e. age, body mass and stature) and all variants of the dependent variable (i.e. peak $\dot{V}O_2$).

Sex differences criteria measurements were analysed using one-way analysis of variance (OW-ANOVA). The level of statistical significance was accepted as $p<0.05$.

Results

Physical characteristics and physiological responses at peak $\dot{V}O_2$. The physical characteristics and the physiological responses at peak $\dot{V}O_2$ are summarised in Table 1. In the main, the male athletes were taller, had higher body mass and ventilation rates at peak $\dot{V}O_2$ than the female athletes but there was no sex difference in maximal exercise HR and RER at peak $\dot{V}O_2$

The main finding was that the occurrence of a $\dot{V}O_2$ plateau phenomenon at volitional exhaustion during treadmill running was significantly higher in female and than in male athletes (i.e. 64% versus 53%). This was despite the male subjects having significantly higher absolute (L/min) and ratio-normalised (ml/kg/min) peak $\dot{V}O_2$ than the female subjects.

Table 1
Physical characteristics and physiological responses at peak $\dot{V}O_2$ in male and female athletes

Variables	Male athletes (n=158)	Female athletes (n=28)
Age (yrs)	21.7±4.9	21.9±7.0
Body mass (kg)	64.8±8.6	53.0±7.0*
Stature (m)	1.72±0.06	1.61±0.07*
Minute ventilation at peak $\dot{V}O_2$ (L/min)	123.7±19.5	87.7±10.6*
Heart rate at peak $\dot{V}O_2$ (beats/min)	190±9	189±9
Respiratory exchange ratio at peak $\dot{V}O_2$	1.11±0.05	1.10±0.04
Occurrence of a $\dot{V}O_2$ plateau	83(53%)	18(64%)*
Satisfaction of two of three (i) RER>1.10, (ii) HR at test termination > 95% of age predicted HR_{max}, (iii) volitional exhaustion	100%	100%

*Denotes significant sex difference at $p<0.05$; $\dot{V}O_2$ is oxygen uptake; RER is respiratory exchange ratio. HR_{max} is maximum heart rate given by 220-age (yrs)

Discussion

The present study examined the occurrence of $\dot{V}O_2$ plateau in an incremental treadmill run test to volitional exhaustion for the purpose of the determination of maximal oxygen uptake in a large group of trained male and female athletes.

There are few data on the $\dot{V}O_2$ plateau phenomenon in large numbers of trained athletes as the majority of studies that had examined the issue had been on relatively small numbers of subjects and had focused primarily on healthy rather than trained subjects. Peak $\dot{V}O_2$ data for the male and female athletes in the present study could be described as modest to average for trained athletes, with many studies reporting higher values in male and female athletes [5,8]. The results also showed the occurrence of the $\dot{V}O_2$ plateau phenomenon was evident only in 53% of the 158 male subjects (peak $\dot{V}O_2$ =58.0±6.9 ml/kg/min) and 64% of the 28 female subjects (peak $\dot{V}O_2$ =48.4±7.2 ml/kg/min) tested. This contrasted with 39% of elite male athletes (peak $\dot{V}O_2$ =79.1±0.7 ml/kg/min) and 25% of elite female athletes (peak $\dot{V}O_2$ =66.1±1.2 ml/kg/min) in an equivalent study reported by Docherty *et al.* [5], using the same $\dot{V}O_2$ plateau criterion. Taken together, these data suggest that the hypothesis articulated by Wagner [11] that subjects with a higher peak $\dot{V}O_2$ are more likely to demonstrate a $\dot{V}O_2$ plateau during a maximal exercise effort appears untenable. Indeed the female subjects in the present study with lower mean peak $\dot{V}O_2$ than the male subjects demonstrated a higher occurrence of a $\dot{V}O_2$ plateau. Clearly, the popular view that a lack of motivation on the part of subjects to give a maximal effort during testing, as a reason for the non-occurrence of a $\dot{V}O_2$ plateau [11] was not supported by the data in the present study. This is especially when the other criteria for the elicitation of a maximal exercise effort were achieved. For instance, both male and female subjects achieved two out of three (100%) criteria for maximal exercise exertion at test termination. Other reasons why a $\dot{V}O_2$ plateau occurs in some subjects and not others must be sought but it appears that training status was not a key factor. There is some speculation that maximal anaerobic power may be a factor which explains why a plateau occurs in some subjects but not in others, that subjects who generate greater anaerobic power are more likely to demonstrate the occurrence of an oxygen plateau at exhaustion. Although maximal anaerobic power was not assessed in the present study, there are ample data which show that adult male subjects demonstrate greater anaerobic power than female subjects [2,4,7]. However, the abovementioned assertion was not supported by the present data since a higher percentage of female subjects than male subjects demonstrated a $V0_2$ plateau at exhaustion. Given that a $V0_2$ plateau at exhaustion during incremental exercise is not always tenable, it is highly recommended that it should not be used as a criterion for the attainment of maximal oxygen uptake. Instead, the satisfaction of i) RER >1.05, ii) HR at test termination of >95% of age-predicted HR_{max} (based on 220 minus age in years) and (iii) exercising to volitional exhaustion (i.e. unsteady running gait and/or facial flushing) appear more tenable, since in the present study, 100% of the male and female athletes achieved two out of the abovementioned three criteria for maximal exercise exertion at test termination.

In summary, the present data showed that $\dot{V}O_2$ plateau during an incremental treadmill run to volitional exhaustion occurred in 53% and 64% of trained male and female athletes, respectively, despite other criteria for the attainment of a maximal exercise effort being satisfied. The absence of a $\dot{V}O_2$ plateau was not due to poor motivation or was it due to the failure of subjects to tolerate fatigue.

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