ORIGINAL RESEARCH ARTICLE

Impact of training status on maximal oxygen uptake criteria attainment during running

Candice Jo-Anne Christie (BA, HMS, BSc (Med)(Hons), MSc, PhD)
Briar Ingram Lock (BA, Hons)

Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown

Abstract

Objectives. The aims of this study were to assess whether training status influenced maximal physiological and perceptual responses and whether certain maximal criteria were more sensitive for individuals with different levels of training.

Methods. Males who were either trained (*N*=8) or untrained (*N*=9) underwent a maximal treadmill test to assess whether the criteria to indicate VO2 max were training-specific.

Results. $VO2_{max}$ was significantly higher in the trained (70.0 $mlO_2.kg^{-1}.min^{-1}$) compared with the untrained group (54.5 $mlO_2.kg^{-1}.min^{-1}$). Only 11% of the trained and 56% of the untrained individuals achieved a plateau in the oxygen uptake curve. Peak treadmill running speed was significantly faster and total test time significantly longer in the trained group. In contrast, peak lactate, although maximal for both groups, was significantly higher in the untrained group (13.5 $mmol.l^{-1}$ compared with 10.3 $mmol.l^{-1}$). The other responses were not different between the groups. Noteworthy is that none of the subjects achieved all of the criteria indicating a maximal effort. The criteria most achieved in both samples were HR_{max}, RPE_{max} and La_{max} with the latter being the most attained in the untrained group and RPE_{max} being mostly attained by the trained group.

Conclusions. The criteria used to indicate attainment of $VO2_{max}$ may be limited and may differ when comparing a heterogeneous training sample. Although $VO2_{max}$ was significantly higher in the trained group, responses were different for O_2 plateau attainment and La_{max} but similar for the other British Association of Sports Sciences criteria. It may be concluded that the physiological variables coinciding with maximal effort may differ in individuals with different levels of training.

CORRESPONDENCE:

Candice Christie
Department of Human Kinetics and Ergonomics
PO Box 94
Rhodes University
Grahamstown
6140 South Africa
Tel. +27 (46) 603-8470
Fax. +27 (46) 622-3803
E-mail: c.christie@ru.ac.za

Introduction

Maximal oxygen uptake provides a highly reproducible measure of aerobic capacity only if rigid criteria for determining the attainment of $VO2_{max}$ are applied.[1] Standard criteria for the termination of a maximal test were established by the British Association of Sports Sciences.[2] According to these standards, the physiological and perceptual responses measured at exhaustion can be considered maximal if the increase in VO_2 with increasing work rate exhibits a plateau, if heart rate (HR) is within 10 $b.min^{-1}$ of the age-predicted maximum, if the respiratory ratio (RER) is greater than 1.15, if peak blood lactate (La) concentration is above 8 $mmol.l^{-1}$ and if the individual is perceived to be exhausted with a rating of perceived exertion (RPE) equal to, or higher than 18.[2] If these criteria are not achieved, the VO_2 value at maximum is referred to as $VO_{2\ peak}$.

Although these criteria have been used extensively, there has been controversy surrounding the validity of them to indicate maximal effort.[3] In addition to this, although there is a wealth of information comparing the VO_{2max} values of trained and untrained individuals, there is limited information comparing whether the other maximal criteria are met similarly in groups with differing levels of training. This investigation thus sought to compare not only the VO_{2max} values of trained versus untrained individuals, but also other maximal physiological and perceptual responses obtained during a continuous, incremented treadmill test. Also, the frequency of achievement of the various VO_{2max} criteria between the two groups of subjects was evaluated. The hypothesis proposed was that trained individuals would achieve a higher maximal oxygen uptake than their untrained counterparts. Furthermore, it was proposed that the remaining maximal British Association of Sport Sciences criteria (HR, RER, La, and RPE) as well as peak treadmill running speed and total test time would differ between the trained and untrained groups.

Methods

Eight trained and 9 untrained male subjects aged 18 - 25 years were recruited from a university student population. The study was approved by the Ethics Committee of the Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown. Each subject provided written informed consent and basic measures were obtained (Table I). All subjects were of a similar age, stature and mass, and BMI values fell within the 'normal', healthy range for young males. Selection criteria for the trained subjects included participation in endurance training at least 3 times a week for the 3 months prior to testing and completion of at least 1 half-marathon in that time period. With regards to the untrained subjects, only individuals who reported no regular or occasional aerobic exercise (above that required for daily activities) for the 3 months prior to testing were selected.

TABLE I. Descriptive characteristics of the subjects

	Trained (*N*=8)	Untrained (*N*=9)
Age (yrs)	22.0±1.7	21.6±1.4
Height (cm)	181.1±4.8	178.1±3.5
Weight (kg)	75.3±8.3	77.3±5.1
BMI ($kg.m^{-2}$)	22.9±2.6	24.2±1.8

BMI = body mass index.

Each subject performed 1 maximal test using the same protocol, the progressive speed protocol (PSP). Participants had to avoid extreme climates 36 hours before testing and were instructed to avoid alcohol, medication and strenuous exercise in the 24 hours prior to the test session. The progressive speed protocol, originally described by Matter *et al.*[4] started at a speed of 12 $km.h^{-1}$ which was maintained for 1 minute.[5] The speed of the treadmill was then increased by 1 $km.h^{-1}$ every minute thereafter until volitional exhaustion. According to McArdle *et al.*[6] motivational factors play a major part in achieving maximal performance and therefore subjects received strong verbal encouragement throughout the entire test. This encouragement was consistent for all the tests and involved notifying the subjects of the amount of time left to complete each speed. Expired air was continuously sampled during the test (Quark b^2, Cosmed, Italy) and before each test the gas meters were calibrated with a gas mixture containing 4.9% CO_2 with the remainder made up of a N_2/O_2 mixture.

On arrival at the laboratory subjects were fitted with a Polar Sports Tester heart rate monitor (Polar Electro, Kempele, Finland) and the face mask for the Quark b^2, which were both fastened securely. Subjects were required to perform a 5-minute warm-up on a stationary cycle ergometer at their own chosen intensity. According to Shephard,[7] a brief warm-up reduces the risk of musculoskeletal injuries and electrocardiographic abnormalities, while yielding greater VO_{2max} values. The subjects were then instructed to carry out a stretching routine, with particular focus on the quadriceps, hamstrings and gastrocnemius muscles. When this had been completed, the mouthpiece for expired gas analysis was attached to the mask.

Although specific criteria have been developed by the British Association of Sport Sciences[3] to indicate when VO_{2max} has been achieved, test termination in this investigation was exclusively dependent on volitional fatigue. Accordingly, participants had to stop the test and straddle the treadmill when they felt they had reached their maximum effort. However, as it was imperative that subjects reached maximum effort, it was explained that they needed to keep running until they felt they could no longer continue and they were verbally motivated to push to maximum and continue for as long as possible during the test. The highest VO_2 recorded during any interval was recorded as the individual's $VO_{2\ peak}$. Heart rate was recorded continuously during the test by a Sports Tester heart rate monitor. Maximal heart rate (HR_{max}) was defined as the heart rate at the time of test termination. Central ratings of perceived effort were recorded every minute using the Borg Scale.[8] The scale grades levels of exhaustion from a rating of 6 (resting) to a rating of 20 (maximal effort). The RER was measured throughout the test and lactate (Accutrend, Roche Diagnositics, USA) was measured and recorded via the 'pin prick' method from the left ring finger on termination of the test while the subject was still straddling the treadmill.

TABLE II. Maximal oxygen uptake ($VO_{2\ max}$: $mLO_2.kg^{-1}.min^{-1}$) maximal heart rate (HR_{max}: $beats.min^{-1}$), maximal respiratory exchange ratio (RER), maximal rating of perceived exertion (RPE), peak treadmill running speed ($km.h^{-1}$) and time taken to complete the protocol (min)

	Trained (*N*=8)	Untrained (*N*=9)
VO_{2max}	70.0±7.2	54.5±3.6*
HR_{max}	196±10	199±9
RER_{max}	1.13±0.09	1.07±0.06
La_{max}	10.3±4.6	13.5±2.4*
RPE_{max}	20.0±0.5	18.0±1.5
Peak speed	19.8±1.4	16.3±1.0*
Test duration	9.12±1.4	5.12±1.2*

*Significant difference (p <0.05).

Statistical analysis

All data were expressed as means ± standard deviation (SD). Maximal physiological and perceptual values between groups were compared using a *t*-test for independent samples. The level of significance was set at $p<0.05$.

Results

There was no significant difference in age, stature, mass and BMI between the samples (Table I). Table II shows that trained subjects reached significantly higher ($p<0.05$) maximal oxygen uptake values (70.0 $ml.kg^{-1}.min^{-1}$) than the untrained subjects (54.5 $ml.kg^{-1}.min^{-1}$), demonstrating that the selection criteria with regards to training status were accurate. However, the large standard deviation in VO_{2max} for the trained subjects (7.2 $ml.kg^{-1}.min^{-1}$) implies that these subjects were possibly of differing levels of training. Fewer of the trained subjects (11%) demonstrated a plateau in oxygen uptake compared with the untrained subjects (56%). Although the two groups reached similar maximal HR values, large standard deviations in HR_{max} were evident for both trained (10 $b.min^{-1}$) and untrained (9 $b.min^{-1}$) groups, highlighting the inter-individual variability of this measure. No significant differences in maximal RER responses were found between the two samples with both samples below the criteria of 1.15 (Table II). The lactate concentration was significantly higher in the untrained subjects (13.5 $mmol.l^{-1}$) than the trained individuals (10.3 $mmol.l^{-1}$). Perceptual responses were maximal (≥18) and similar for both sets of participants. Significant differences between the trained and untrained individuals were also evident for peak treadmill running speed and test duration. Overall, the trained group reached

TABLE III. Percentage (%) of trained compared with untrained runners who met the BASS criteria as well as the magnitude of the difference in criteria attainment between the two groups

	Trained (*N*=8)	Untrained (*N*=9)	Magnitude of the difference between samples (%)
VO_2 plateau	11	56	18
HR_{max} ($b.min^{-1}$)	67	89	18
RER_{max}	67	33	28
La_{max} ($mmol.l^{-1}$)	89	100	9
RPE_{max}	100	67	27

a higher peak treadmill running speed (19.8 km.h^{-1} compared with 16.3 km.h^{-1}) and ran for approximately 4 minutes longer than their untrained counterparts.

Table III shows that the percentage attainment of the British Association of Sport Sciences criteria differed considerably between the trained and untrained subjects. Only 11% of the trained individuals and 56% of the untrained subjects met the criteria for VO_2 plateau. Thus a total of only 34% of the subjects achieved the criterion of a plateau in oxygen uptake, suggesting that this is a poor criterion to indicate maximal effort. The HR criterion was achieved by more of the untrained subjects while the RER criterion was achieved by more of the trained subjects. All the trained subjects met the RPE criteria, while only 67% of the untrained subjects attained this criterion. The lactate criterion was met by all of the untrained subjects but not by all of the trained individuals (89%). Overall, a higher percentage of the trained individuals met the British Association of Sport Sciences criteria for RER and RPE and a greater percentage of the untrained individuals met their criteria for HR, VO_2 plateau and lactate.

Discussion

The most important finding of this study was that a higher percentage of the trained individuals met the British Association of Sport Sciences criteria for RER and RPE and a greater percentage of the untrained individuals met the criteria for HR, VO_2 plateau and lactate. This implies that perceptual responses are possibly more important for determining the point of maximum exhaustion specifically in trained individuals whereas physiological responses, particularly lactate, give a better indication of maximal effort in less trained individuals. An important finding was that of the 18 subjects who participated in the study, none of them met all 5 criteria prescribed by the British Association of Sports Sciences.[2] The lactate criterion was the most easily achieved standard, with 94% of total subjects attaining a La_{max} of greater than 8mmol.l^{-1}. This suggests that the lactate criterion is the most accurate marker of maximal effort, a finding supported by Jacobs[9] and Howley *et al*.,[10] who maintain that variations in exercise performance are more accurately explained by lactate-related variables compared with other variables including VO_{2max}. Consequently the lactate criterion should be more widely used to indicate when VO_{2max} has been achieved, especially in the absence of a VO_2 plateau.

Although the HR standard was met by 78% of all subjects, this criterion should not be used to confirm the attainment of VO_{2max} because it had a high inter-individual variability. The RER standard was only achieved by half of the subjects who participated in this experiment. The inability of all individuals to reach the RER criterion even when a plateau in VO_2 is exhibited corresponds to findings by Howley *et al*.[10] Therefore, the RER criterion, like the VO_2 plateau standard, is not a consistent marker of maximal effort.

Not all of the untrained subjects fulfilled the British Association of Sports Sciences criteria for RPE although it did appear that they were exhausted at the end of the maximal test. The failure of some of the untrained subjects to attain this standard could be attributed to incorrect ratings of perceptual responses and a suppression of feelings of fatigue. Thus the RPE criterion in itself is not an unreliable marker of maximal effort, particularly in well-trained athletes. However, in order to ensure the reliability of this standard, it is vital that all subjects have a comprehensive understanding of the concept of RPE.

From this investigation it would appear that the criteria for lactate, RPE and HR should be used in combination to accurately determine the attainment of maximal oxygen uptake. This is because these three standards were met by most of the subjects. Contrastingly, it has been documented that the use of the RER and lactate criteria together increase the probability that VO_{2max} is achieved.[11] This inconsistency in results highlights the need to determine which of the BASS criteria, and in which combinations accurately determine the achievement of maximal oxygen uptake, because it may vary between trained and untrained individuals.

The differences in the attainment of the British Association of Sports Sciences criteria between the two samples (Table III) were greatest for RER and RPE, implying that these standards are unreliable markers of maximal effort when comparing trained and untrained groups. An 18% difference in the attainment of HR and VO_2 plateau between the two samples was also apparent, indicating that these two criteria are also unreliable for this type of comparison. There was only a 9% difference in the attainment of the lactate criterion between the trained and untrained individuals, suggesting that this criterion is the most reliable when comparing trained and untrained people at maximal effort. However, it has been postulated that La_{max} values vary considerably,[12] especially among athletes with similar abilities, which undermines the ability of this variable to predict VO_{2max}.[13]

These data should be interpreted in the context of the differences in training status of the two groups. Although the trained subjects had significantly higher maximal oxygen uptakes, there was only a difference of 12%. Typically, endurance athletes have VO_{2max} values approximately 40% higher than their sedentary counterparts.[6] This can be explained by the fact that the majority of the trained subjects were not elite athletes, having only competed at university and provincial levels. Conversely, some of the untrained subjects may be genetically predisposed to superior performance, as it is well known that differences in VO_{2max} between individuals often result from genetic, as opposed to training factors.[6,7,14] This suggests that in a heterogeneous sample, VO_{2max}, peak treadmill running speed (workload) and total test time are likely to be significantly higher in trained individuals while the other responses, excluding lactate, are likely to be similar. In addition, trained individuals are less likely to achieve the criterion of a plateau in the O_2 uptake curve.

Data from this study acknowledge that the criteria prescribed by the British Association of Sports Sciences[2] for the termination of a maximal test cannot be accurately applied to both trained and untrained people, suggesting a revision of standards may be necessary. It is recommended that these criteria be adjusted with reference to the apparent differences in maximal physiological and perceptual responses between trained and untrained people.

The discrepancies observed in the attainment of the British Association of Sports Sciences criteria confirm the findings of St Clair Gibson *et al*.[3] that these criteria are not always met, despite subjects reaching levels of maximal exhaustion. However, because test termination was based on volitional fatigue, one cannot negate the possibility that the test was stopped before maximal values were achieved, particularly in the untrained subjects. This could have accounted for some of the differences found in criteria attainment between the trained and untrained individuals. Nevertheless, numerous studies have substantiated that the criteria used to assess the attainment of VO_{2max} are limited.[3,7,10,11,15,16] Consequently the British Association of Sports Sciences criteria used to demonstrate the attainment of VO_{2max} must be used with caution, especially when the sample group includes both trained and untrained individuals.

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