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Confirming Maximal Oxygen Uptake: Is Heart Rate the Answer?

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Key word
plateau, criteria, verification, cardiac response, VO_{2max}

accepted 02.10.2017

Bibliography
DOI https://doi.org/10.1055/s-0043-121148
Published online: 24.1.2018
Int J Sports Med 2018; 39: 198–203

ISSN 0172-4622

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ABSTRACT

This study investigates heart rate (HR), in 11 young adults (22.4 ± 3.21yr), at $\dot{V}O_{2max}$, to ascertain whether measured maximal heart rate (HR_{max}), as determined by a plateau in HR (HR_{plat}), can reliably confirm $\dot{V}O_{2max}$. $\dot{V}O_{2max}$ and HR_{plat} were determined, using the parameters of a $\dot{V}O_2 \leq 50\,ml \cdot min^{-1}$ and a $\Delta HR \leq 2b \cdot min^{-1}$, respectively, over the final 60 s of sampling. $\dot{V}O_2$ was also independently determined using a verification phase protocol. A HR_{plat} was achieved by 91 % of participants ($\Delta HR = 1.3 \pm 1b \cdot min^{-1}$) and critically the time at which HR_{max} was reached coincided with that at which $\dot{V}O_{2max}$ was achieved. Moreover RER and ΔRER criteria were reached significantly earlier ($p < 0.05$) than $\dot{V}O_{2max}$, whilst age-related heart rate maximums (HR_{age}), were not achieved by many participants. The results suggest that a $HR_{plat} \leq 2\ b \cdot min^{-1}$ is a more accurate method, within the group tested, to determine whether a 'true' $\dot{V}O_{2max}$ has been achieved, than other secondary criteria and potentially avoids the requirement for an additional verification phase.

Introduction

$\dot{V}O_{2max}$ measurements are widely used for the assessment of physiological responses to exercise and training [26, 51] and cardiorespiratory health [38, 59]. However the attainment of $\dot{V}O_{2max}$ typically requires participants to exercise until volitional exhaustion [57]. A problem arises, therefore, in identifying those participants who terminate the test prematurely and may not have elicited a 'true' $\dot{V}O_{2max}$. Classically, $\dot{V}O_{2max}$ is based on the levelling off, or plateau, in oxygen uptake ($\dot{V}O_{2plat}$), despite a continued increase in exercise intensity [2, 3, 7, 21, 22, 54, 58]. Whilst $\dot{V}O_{2plat}$ is considered to be the primary criterion, in establishing a 'true' $\dot{V}O_{2max}$ [21, 49], multiple studies report considerable variation in the attainment of $\dot{V}O_{2plat}$ [5, 11, 12, 16–18, 28, 43–45, 50, 58, 61]. Possible explanations for this include methodology, such as $\dot{V}O_2$ sampling intervals [4, 33, 46], protocol duration [5, 28, 45], modelling approaches [10, 46] and populations tested [11, 44, 54, 58]. To compensate for the absence of a definitive plateau, researchers have adopted a variety of secondary criteria, to help ascertain that a 'true' $\dot{V}O_{2max}$ has been achieved [1, 6, 33]. Unfortunately none of these criteria have proved reliable [4, 39]. Beltrami et al. [8] demonstrated that 71 % of the plateaus detected were, in fact, 'false-positives', despite being 'confirmed' by RER and HR_{age} values. Similarly not achieving a plateau may not be an indication that a maximum effort has not been made or, indeed, that a 'true' $\dot{V}O_{2max}$ was not achieved [6, 29, 43, 48]. Furthermore it has been demonstrated that participants, performing identical incremental tests, can demonstrate a plateau in only one test, despite showing no significant differences in absolute $\dot{V}O_2$ [27, 32, 34, 36]. Such findings question the basis of using $\dot{V}O_{2plat}$ as the 'gold standard' indicator of a 'true' $\dot{V}O_{2max}$ and that a different approach is required. One such method is the verification phase [32, 34, 35, 47, 55] which contends that a 'true' $\dot{V}O_{2max}$ is exhibited if the $\dot{V}O_{2max}$ achieved during a supramaximal verification phase is equal to, or lower, than the $\dot{V}O_{2max}$ in the initial, incremental, test.

Midgley et al. [32] further showed that if HR_{max}, agreed within $2b \cdot min^{-1}$ in incremental and verification phases, this provided a high degree of confidence that a maximal effort had been given in the incremental phase. A number of studies have used HR_{plat} to help

determine individuals' HR_{max} and hence confirm $\dot{V}O_{2max}$. [30, 32, 34, 35]. The rationale being that when undertaking an incremental test, followed by a verification phase, it is improbable that a similar HR_{plat} will be achieved unless a maximal effort has been given in both trials. Accordingly a reproducible HR_{plat} can confirm whether a 'true' $\dot{V}O_{2max}$ was achieved in the initial incremental test. Hence, by extension, HR_{plat} could be used as a robust 'stand-alone' criterion for determining that a 'true' VO_{2max} has been achieved, even in the absence of primary $\dot{V}O_{2plat}$. Accordingly the aim of this investigation is to use the established $\dot{V}O_{2max}$ verification phase technique to determine whether HR_{plat} is a reliable indicator of $\dot{V}O_{2max}$ and to compare its performance with other secondary criteria used for the establishment of VO_{2max}, namely $\dot{V}O_{plat}$, RER, ΔRER and HR_{age}. If this is found to be the case it will demonstrate, for the first time, that HR_{plat} can be used as a 'stand-alone' method to confirm $\dot{V}O_{2max}$.

Methods

Following institutional ethical approval that meets the standards of this Journal [19], eleven individuals (9 men, 2 women) volunteered and consented to participate. Age, mass, stature and $\dot{V}O_{2max}$ were (mean ± SD); 22.4 ± 3.21yr., 70.7 ± 10.5 kg, 170.1 ± 7.4 cm, 51.6 ± 4.47 ml • kg^{-1} • min^{-1}, respectively. Given the novel approach it was felt appropriate to limit the study to young, recreationally active adults. Participants attended the laboratory for 3 separate test sessions, each visit separated by at least 48 h, with all visits at the same time of day, to minimize diurnal variations. The first visit was a habituation trial to confirm that all participants met the minimum fitness criteria of $\dot{V}O_{2max} \geq$ 40 ml • kg^{-1} • min^{-1}. Experimental data was obtained during visits 2 and 3. Before testing participants were informed that they should have eaten no less than three hours prior to the test visit and also ensure that they arrived in a hydrated state, without having consumed alcohol, or caffeine, within the last 24 h. They were also requested not to complete any heavy training sessions within 48 h, either side of testing.

Data Collection

Heart rate was recorded throughout the duration of each trial using a short-range telemetric monitoring system (Polar 810 s, Kemple, Finland) and averaged on a 5 s basis [16, 17]. Following a self-paced, low intensity, treadmill warm-up, incremental $\dot{V}O_{2max}$ tests were completed on a pre-calibrated treadmill (HPcosmos, Quasar Med.,Germany). To ensure consistency, participants' duration and intensity of warm-ups was recorded, during the habituation visit and standardised in subsequent trials. For both test and verification protocols treadmill speed was kept constant throughout the test, with male and female participants running at 12 km • h^{-1} and 10 km • h^{-1}, respectively, with the gradient starting at 0 % and increasing by 1 % • min^{-1} until volitional exhaustion. Following test termination, participants were allowed 6 min passive recovery [34], after which they undertook a verification phase which consisted of a supra-maximal effort, at a gradient 1 % greater than that of the preceding test termination, to volitional exhaustion. During all trials, gas-exchange variables ($\dot{V}O_2$, $\dot{V}CO_2$, VE and RER) were recorded, on a breath-by-breath basis, using a pre-calibrated metabolic cart (MSX671, Ferraris Respiratory, UK) [16, 17]. The coefficient of variation for $\dot{V}O_{2max}$, using participants of similar age and training status within our laboratory is 3.4 % [16, 17], which concurs with similar studies [5, 32]

Data Analysis

HR_{age} was calculated using the formulae; 220-age and the equations of Inbar et al. [25] and Tanaka et al. [53]. Raw data was filtered, using a custom designed spreadsheet and values exceeding ± 2SD of mean $\dot{V}O_2$, were deleted. Filtered data was averaged, over the final 2 min, for both trial and verification phases, with the highest 30 s value being classed as $\dot{V}O_{2max}$. HR data was processed over the final two minutes, with HR_{max} being defined as the maximum sustainable heart rate, averaged over a minimum of 10 s. $\dot{V}O_{2plat}$ and HR_{plat} were calculated as the change in $\dot{V}O_2$ and HR ($\Delta\dot{V}O_2$, ΔHR) between the final two 30 s values.$\dot{V}O_{2plat}$ was established according to 2 accepted criteria; a $\Delta\dot{V}O_2$ of ≤ 50 ml • min^{-1} and a $\Delta\dot{V}O_2$ of ≤ 100 ml • min^{-1} over the final two consecutive 30 s sampling periods [15–17, 34]. Similarly HR_{plat} achievement was estimated using, either a ΔHR ≤ 2b • min^{-1}, or a ΔHR ≤ 4b • min^{-1} over the final two 30 s intervals for both $\dot{V}O_{2max}$ and verification tests [16, 17, 35].

Statistical Analysis

Statistical analysis was completed using SPSS (Version 20.0, Chicago, Illinois, USA). All 4 datasets (n = 11) were normally distributed and displayed homogeneity of variance using Shapiro-Wilks and Levine tests, respectively. Repeat measures analysis of variance (ANOVA) was used to test the null hypothesis that there were no differences between data from the $2\dot{V}O_{2max}$ trials and their respective verifications. For HR data, or their verifications, two-tailed, paired sample t-tests, were employed to assess the same null hypothesis.

As there were no significant differences between Trials 1 and 2, for both primary and secondary criteria, all data was consolidated to form a single data set for further analysis. Here individual responses were manually compared, to determine which met the defined threshold criteria ($\dot{V}O_{2plat}$, HR_{plat}, HR_{age}, RER and ΔRER). Finally the times at which HR_{max}, $\dot{V}O_{2max}$, RER and ΔRER were achieved were compared using two-tailed paired t-tests to assess the null hypothesis that there was no difference between the times at which these individual parameters were achieved. Alpha level for all statistical analyses was set at $p \leq 0.05$.

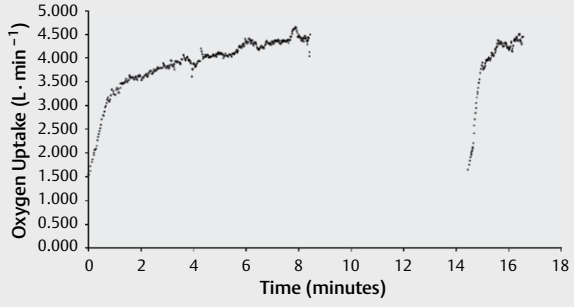
Results

A typical incremental trial and subsequent verification test is shown in ▶ **Fig. 1**. The group mean value for $\dot{V}O_{2max}$ during the incremental trials was significantly greater than the $\dot{V}O_{2max}$ attained in the verifications (▶ **Table 1**). Whilst there were no significant differences between the data collected in Trials 1 and 2, there were significant differences between the trials and their respective verifications in all parameters, with the exception of $\Delta\dot{V}O_2$ and VE_{max}.

HR_{maxs} were significantly higher in the $\dot{V}O_{2max}$ trials, than in the verification phases. Calculated HR_{age} (220-age) was significantly higher, than recorded HR_{maxs} in both trial and verification phases (▶ **Table 1**), However calculated HR_{ages}, [25, 53] were not significantly different, from measured HR_{maxs}, in the incremental trials,

but significantly higher than in the verifications. ΔHR, recorded during the trials was also significantly lower (1.3 ± 1b • min^{-1}), than in the verifications (> 6b • min^{-1}). Finally mean RER and ΔRER were both significantly greater in the trials, than the verifications, with trial means exceeding the values typically used in threshold criteria (▶ **Table 1**).

Data in ▶ **Table 2** demonstrates that the number of participants who satisfied each criterion was dependent on the stringency of the threshold value, with increasing numbers 'confirming' $\dot{V}O_{2max}$ as the criteria were relaxed. Critically HR_{plat} (≤ 2b • min^{-1}) was achieved on 20 out of 22 trials and only twice in verifications and in one instance this was for a participant whose verification $\dot{V}O_{2max}$ exceeded trial $\dot{V}O_{2max}$. Since this participant's mean HR_{max} was 21b • min^{-1}, more than 3 standard deviations, below their calculated HR_{age} [25] there is a sound case to exclude their data. The less stringent criteria of 4b • min^{-1} was achieved by all participants, in the trials and in 7 verifications. HR_{age} (220-age) was a poor indicator of attainment of $\dot{V}O_{2max}$, with only 5 of 22 trials achieving this target. Moreover this same target was achieved in 4 of the verifications. Other HR_{age} targets proved more attainable and did not differ significantly from measured HR_{maxs} (▶ **Table 1**). Despite this, target HR_{ages} were only met 11 and 13 times in the trials for calculated values [25, 53] and were also met in 4 and 8 instances, in the verifications. Superficially an RER (≥ 1.1) appeared a useful metric for confirming $\dot{V}O_{2max}$ with 21 and 5 instances of attainment in the trials and verifications, respectively, whilst achievement of the more stringent RER requirement of ≥ 1.15 produced results broadly comparable to HR_{plat} (≤ 2b • min^{-1}). However RER was found to occur significantly earlier ($P < 0.05$), in the trials, than either $\dot{V}O_{2max}$ or HR_{max}. A similar, but more marked situation was noted for ΔRER ($p < 0.01$; ▶ **Table 2**; ▶ **Table 3**). Critically attainment times for $\dot{V}O_{2max}$ and HR_{max} were found to be effectively coincident, differing by less than 3 %, a non-significant difference. Moreover HR_{max} was achieved at a significantly later time, in the incremental trials, than both RER and ΔRER, whilst both these parameters were reached significantly earlier than $\dot{V}O_{2max}$, attainment (▶ **Table 3**).



▶ **Fig. 1** Typical oxygen uptake response for a single participant during a representative $\dot{V}O_{2max}$ test ($\dot{V}O_{2max}$ = 4.8l • min^{-1}) and subsequent verification trial (4.4l • min^{-1}). Each point represents a single breath. Group data for $\dot{V}O_{2max}$ was significantly lower in the verification phase ($p < 0.01$).

Discussion

All the physiological parameters measured in this study and/or their frequencies of occurrence are comparable with those of similar, previous, studies [16, 17, 33, 34, 46, 61]. Numerous studies have demonstrated that currently employed secondary criteria are unable to reliably distinguish between a 'true' $\dot{V}O_{2max}$ and a submaximal oxygen uptake in all tested participants [4, 8, 33]. Such findings were confirmed by this study. Furthermore it confirmed previous findings [8] that a $\dot{V}O_{2plat}$, can be achieved at sub-maximal $\dot{V}O_2$. Critically the results of this study support the experimental

▶ **Table 1.** Mean data (± SD) for all incremental $\dot{V}O_{2max}$ trials and their corresponding verifications.

Parameter	$\dot{V}O_{2max}$ Trial 1	$\dot{V}O_{2max}$ Trial 2	Verification 1	Verification 2
Time of trial (mins)	8.8 ± 1.42	8.5 ± 1.52	1.9 ± 0.35	2.1 ± 0.52
$\dot{V}O_2$ (l • min^{-1})	3.7 ± 0.77 * 1	3.6 ± 0.64 * * 2	3.5 ± 0.65	3.5 ± 0.51
$\dot{V}O_{2max}$ (ml • kg − 1 • m in − 1)	52.7 ± 5.64 * * 1	51.6 ± 4.42 * * 2	49.7 ± 4.30	49.2 ± 3.94
$\Delta\dot{V}O_2$ (ml • min − 1)	60.7 ± 56.42	70.5 ± 58.94	119.4 ± 89.22	113.6 ± 141.72
$\dot{V}CO_2$ (l • min − 1)	4.1 ± 0.82 * * * 1	4.1 ± 0.81 * * 2	3.5 ± 0.71	3.6 ± 0.63
VE_{max} (l • min − 1)	127.0 ± 24.47	125.8 ± 25.25	126.8 ± 25.05	128.0 ± 23.28
HR_{max} (b • min − 1)	191.2 ± 7.80 * * 1	189.9 ± 9.10 * 2	186.9 ± 7.44	185.4 ± 8.63
HR (220-age, b • min − 1)	197.5 ± 3.20$1	197.5 ± 3.20$1	197.5 ± 3.20$2	197.5 ± 3.20$2
HR (Tanaka, b • min − 1)	192.3 ± 2.24	192.3 ± 2.24	192.3 ± 2.24$2	192.3 ± 2.24$2
HR (Inbar, b • min − 1)	190.4 ± 2.20	190.4 ± 2.20	190.4 ± 2.20**$1**	190.4 ± 2.20**$1**
ΔHR (b • min − 1)	1.2 ± 0.73 * * * 1	1.4 ± 1.02 * * 2	6.7 ± 3.08	6.4 ± 3.79
RER@VO_{2max}	1.2 ± 0.10 * * 1	1.2 ± 0.06 * * 2	1.0 ± 0.12	1.0 ± 0.09
ΔRER	0.53 ± 0.08 * * * 1	0.54 ± 0.08 * * * 2	0.32 ± 0.10	0.31 ± 0.06
* 1 significant difference at $p < 0.05$ between trial 1 and verification trial 1 * 2 significant difference at $p < 0.05$ between trial 2 and verification trial 2				
* * 1 significant difference at $p < 0.01$ between trial 1 and verification trial 1 * * 2 significant difference at $p < 0.01$ between trial 2 and verification trial 2				
* * * 1 significant difference at $p < 0.001$ between trial 1 and verification trial 1 * * * 2 significant difference at $p < 0.001$ between trial 2 and verification trial 2				
$1 significant difference at $p < 0.05$ between HR_{age} and corresponding HR_{max}				
$2 significant difference at $p < 0.01$ between HR_{age} and corresponding HR_{max}				

▶ **Table 2.** Number of participants satisfying $\dot{V}O_{2max}$, HR_{plat}, RER and ΔRER criteria calculated from data recorded in this study. Also recorded is the number of participants whose measured HR_{max} met, or exceeded the 3 different calculated HR_{age} parameters. For trials and verifications n = 11, for totals, n = 22. N/A = not applicable.

Criteria	Trial 1	Trial 2	Trial Total	Verification 1	Verification 2	Verification total
$\dot{V}O_{2plat}$ ($\leq 50\,ml \cdot min^{-1}$)	6	6	12	3	5	8
$\dot{V}O_{2plat}$ ($\leq 100\,ml \cdot min^{-1}$)	8	8	16	4	8	12
HR_{plat} ($\leq 2\,b \cdot min^{-1}$)	11	9	20	1	1	2
HR_{plat} ($\leq 4\,b \cdot min^{-1}$)	11	11	22	2	5	7
HR_{age} (220-age)	3	2	5	2	2	4
HR_{age} (Tanaka)	7	4	11	2	2	4
HR_{age} (Inbar)	8	5	13	4	4	8
RER (≥ 1.1)	10	11	21	3	2	5
RER (≥ 1.15)	7	11	18	1	1	2
RER (≥ 1.2)	4	7	11	1	1	2
ΔRER (≥ 0.4)	11	11	22	3	0	3
$\dot{V}O_{2max}$ (Trial ≥ Verification)	10	10	20	N/A	N/A	N/A
HR_{max} (Trial ≥ Verification)	10	10	20	N/A	N/A	N/A

▶ **Table 3.** Mean time (± SD) based on consolidated data from trials 1 and 2 for attainment of $\dot{V}O_{2max}$, and other secondary criteria during initial $\dot{V}O_{2max}$ trials.

Measured Parameter	Mean Time of Attainment (mins)	% of Time of $\dot{V}O_{2max}$
$\dot{V}O_{2plat}$	8.1 ± 1.71	100
HR_{max}	8.3 ± 1.51	102.4
RER_{max}	7.6 ± 1.88 * #	93.8
ΔRER	6.9 ± 1.90 * * ##	85.1
Significant difference (* p < 0.05; * * p < 0.01) between time of $\dot{V}O_{2max}$ attainment and time of achievement of other criteria.		
Significant difference (# p < 0.05; ## p < 0.01) between time of HR_{max} and time of achievement of other secondary criteria.		

hypothesis, namely that $HR_{max,}$ as confirmed by the presence of HR_{plat}, coincided with $\dot{V}O_{2max}$ and occurred significantly later, in the incremental exercise tests, than other measured secondary criteria.

Previous work [32, 34, 35] has used HR_{max}, in conjunction with a verification phase, to ascertain achievement of a 'true' $\dot{V}O_{2max}$. Midgley et al. [32] suggested that if HR_{max} values for the incremental and verification phases agreed within $2b \cdot min^{-1}$ of each other, this would provide a high degree of confidence that a subject had given a maximal effort in the incremental phase, irrespective of whether, or not a $\dot{V}O_{2plat}$ was attained. Later work [34, 35] employed a less stringent HR_{max} verification criteria of $< 4b \cdot min^{-1}$. Accordingly HR_{max} verification could replace the current heart rate criterion, based on attainment of $HR_{age,}$ or a fixed percentage of it and other commonly used secondary criteria [1, 6, 23, 24, 33]. However to have confidence in HR_{plat} as a metric for confirming attainment of $\dot{V}O_{2max}$, there should be a clear physiological rationale underpinning the relationship of HR_{plat} with $\dot{V}O_{2max}$.

Such a rationale is a direct consequence of cardiac output (Q) being the ultimate limiting factor of $\dot{V}O_{2max}$ [9, 14]. Since is a function of both stroke volume (SV) and heart rate (HR) it follows that will become limiting when both HR and SV have reached their respective maximums, i. e. . The remaining factor influencing $\dot{V}O_{2max}$ is the efficiency of oxygen unloading in the working tissues [9], reflected by the arteriovenous oxygen difference (avO_{2dif}). Accordingly the relationship between $\dot{V}O_{2max}$ and these parameters can be described by Eq. 1.

$$\dot{V}O_{2max} = (HR_{max} \cdot SV_{max}) \cdot a - vO_{2dif\,max} \quad (1)$$

Given that $\dot{V}O_{2max}$ is a product of these 3 independent factors, it necessarily follows that $\dot{V}O_{2max}$ will be determined by the factor which is the last to become limiting. With respect to $a\text{-}vO_{2dif}$ a number of studies [37, 40–42] report that the partial pressure of oxygen, surrounding the muscle cells decreases, during progressive exercise, until approximately 50 % maximal-workload, after which it remains constant. Hence it is improbable that the avO_{2dif} is the ultimate limiting factor of $\dot{V}O_{2max}$. There is still controversy in the literature as to the precise relationship between SV and $\dot{V}O_{2max}$ [57]. Numerous studies [9, 20, 29, 52, 60] report that SV plateaus at approximately 50-70 % of $\dot{V}O_{2max}$. However some others [13, 56, 60] report small increases in SV, particularly in some elite athletic populations, as $\dot{V}O_{2max}$ is approached. Studies in our laboratory on physically active females ($\dot{V}O_{2max}$ 45.4 ± 4.4 $ml.kg^{-1}.min^{-1}$), using thoracic impedance cardiography, have demonstrated SV plateauing at 60 % $\dot{V}O_{2max}$. Accordingly it is highly likely that the primary limiting variable of $\dot{V}O_{2max}$, certainly in young, non-elite populations, is HR. A key finding of this study was that $HR_{max,}$ as confirmed by HR_{plat}, coincided with $\dot{V}O_{2max}$. This strongly suggests, that if a HR_{plat} is observed in the final stages of an incremental test, then $\dot{V}O_{2max}$ must have been achieved. In the current study HR_{plat} was defined as a $\Delta HR \leq 2b \cdot min^{-1}$ and was achieved in 20 out of 22 instances (21 out of 22 if the anomalous participant is excluded).

The crucial difference between this study and previous work [32, 34, 35] is the demonstration that, rather than using $HR_{age,}$ or $HR_{max,}$ as part of a verification protocol, HR_{plat}, the maximum sustainable HR, has the potential to be used as a 'stand-alone' secondary criterion to confirm a 'true' $\dot{V}O_{2max}$, without the need for a subsequent verification phase.

Another aim of this study was to observe the effectiveness, or otherwise, of some of the current secondary criteria at confirming a 'true' $\dot{V}O_{2max}$ has been achieved. In previous studies [4, 31, 39] between 75 % and 97.5 % of participants achieved an RER ≥ 1.1, whilst between 62.5 %, and 75 % reached HR_{age}. Such values are comparable to the percentages of participants achieving RER ≥ 1.1 and HR criteria in this study. Other work [37, 39] also demonstrated that participants could achieve secondary criteria as early as 73 % of $\dot{V}O_{2max}$ and that only 37.5 % of participants achieved HR_{age}; again results that broadly support the findings of this study. Hence it is apparent that some secondary criteria, particularly HR_{age} were not attainable by all participants, even though a $\dot{V}O_{2plat}$ was evident [4, 8]. Conversely it is also apparent that a $\dot{V}O_{2max}$ test could be terminated prior to reaching $\dot{V}O_{2max}$ [32, 33, 36].

Limitations

Although this study demonstrated that HR_{plat} can be used to confirm a 'true' $\dot{V}O_{2max}$ it is noted that the test group is not reflective of the wider population. Hence future work should investigate diseased populations, also wider age and gender groups, along with different ergometer types.

Conclusions

The key finding of this study was that HR_{plat} potentially provides a valuable, stand-alone, means of determining a 'true' $\dot{V}O_{2max}$, without the need for a verification phase, so confirming and extending previous observations [32, 35].

Accordingly this study provides evidence, subject to further confirmation, for discarding most current secondary criteria used to confirm $\dot{V}O_{2max}$ and their replacement with the simply measured HR_{plat}. Use of this parameter also potentially removes the need for a verification phase.

Acknowledgements

I acknowledge, my employer, Anglia Ruskin University, for providing my co-authors and I the use of their equipment and premises to carry out this research.

Conflict of Interest

The authors has no conflict of interest to declare.

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