Verification phase as a useful tool in the determination of the maximal oxygen uptake of distance runners

Adrian W. Midgley, Lars R. McNaughton, and Sean Carroll

Abstract: This study investigated the utility of a verification phase for increasing confidence that a "true" maximal oxygen uptake had been elicited in 16 male distance runners (mean age (±SD), 38.7 (± 7.5 y)) during an incremental treadmill running test continued to volitional exhaustion. After the incremental test subjects performed a 10 min recovery walk and a verification phase performed to volitional exhaustion at a running speed 0.5 km·h^{-1} higher than that attained during the last completed stage of the incremental phase. Verification criteria were a verification phase peak oxygen uptake ≤ 2% higher than the incremental phase value and peak heart rate values within 2 beats·min^{-1} of each other. Of the 32 tests, 26 satisfied the oxygen uptake verification criterion and 23 satisfied the heart rate verification criterion. Peak heart rate was lower (p = 0.001) during the verification phase than during the incremental phase, suggesting that the verification protocol was inadequate in eliciting maximal values in some runners. This was further supported by the fact that 7 tests exhibited peak oxygen uptake values over 100 mL·min^{-1} (≥ 3%) lower than the peak values attained in the incremental phase. Further research is required to improve the verification procedure before its utility can be confirmed.

Key words: criteria, criterion, plateau, primary, secondary.

Résumé : Cette étude examine la pertinence d'une phase de validation à la suite d'un test d'effort progressif sur tapis roulant jusqu'à épuisement volontaire pour vérifier l'atteinte du « vrai » consommation d'oxygène maximale chez 16 coureurs d'endurance (sexe : m, 38,7 ± 7,5 ans). Pour récupérer après le test d'effort progressif, les sujets marchent durant 10 min puis passent à la phase de validation consistant en une course dont la vitesse est de 0,5 km·h^{-1} plus élevée qu'au dernier palier du test d'effort progressif. Les critères de validation sont : la consommation d'oxygène de pointe égale ou moins de 2 % supérieure à celle du dernier palier, la fréquence cardiaque ne différant pas plus que par 2 batt·min^{-1}. Sur les 32 tests, 26 rencontrent le critère de la consommation d'oxygène et 23 rencontrent celui de la fréquence cardiaque. Durant la phase de validation, la fréquence cardiaque est plus basse que celle observée durant le dernier palier du test d'effort progressif (p = 0.001) suggérant ainsi que le protocole de validation ne permette pas à certains coureurs d'atteindre leur maximum. Ce constat est aussi fait à propos de la consommation d'oxygène : dans 7 tests, la consommation d'oxygène est de 100 mL·min^{-1} (≥ 3 %) plus faible que la valeur de pointe observée au cours du test d'effort progressif. Il faut faire d'autres études pour confirmer la pertinence de la phase de validation.

Mots clés : critères, plateau, primaire, secondaire.

[Traduit par la Rédaction]

Introduction

The maximal oxygen uptake ($\dot{V}O_{2\,max}$) is the maximum rate that oxygen can be used by the body for cellular respiration during intense exercise (Hill and Lupton 1923). Although the $\dot{V}O_{2\,max}$ concept was conceived as early as 1923 (Hill and Lupton 1923), controversy still exists in identifying test procedures that provide a high degree of confidence that a "true" $\dot{V}O_{2\,max}$ has been attained (Day et al. 2003; Duncan et al. 1997; Howley et al. 1995). In healthy individuals, $\dot{V}O_{2\,max}$ may not be attained due to poor effort (Andreacci et al. 2002; Moffatt et al. 1994; Taylor et al. 1955), or because the individual has reached volitional exhaustion before $\dot{V}O_{2\,max}$ has been elicited. This latter problem may occur in relatively short or prolonged tests (Buchfuhrer et al. 1983).

The primary criterion for establishing that $\dot{V}O_{2\,max}$ has been attained is a small or no increase in oxygen uptake ($\dot{V}O_2$) in response to an increase in work rate (i.e., a $\dot{V}O_2$ plateau) (Howley et al. 1995). Taylor et al. (1955) were the first to use the plateau criterion for $\dot{V}O_{2\,max}$ determination. These researchers defined a plateau as an increase in $\dot{V}O_2$ of less than 150 mL·min^{-1} in response to an increase in treadmill grade of 2.5% at 7 miles·h^{-1} (1 mile = 1.6 km). Other studies have since used more conservative values of between 0 and 100 mL·min^{-1} (Cumming and Friesen 1967; Howley et al. 1995; Issekutz et al. 1962), although more liberal values such as 250 mL·min^{-1} have also been used (Cunningham 1990). In the absence of a $\dot{V}O_2$ plateau, secondary criteria allow the investigator to make an informed decision

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as to whether the subject has given a maximum effort and has likely attained $\dot{V}O_{2\,max}$. As reviewed by Howley et al. (1995), the most commonly used secondary criteria have been the attainment of a maximal respiratory exchange ratio (RER_{max}) ≥1.10 and a maximal heart rate (HR_{max}) within 10 beats·min^{-1} of an individual's age-predicted maximum (calculated as 220 – age). However, primary and secondary criteria were developed in studies using specific exercise modalities, test protocols, and subjects (Issekutz et al. 1962; Maritz et al. 1961; Taylor et al. 1955) and several authors have suggested that directly applying these criteria to studies using different methodology is unlikely to be valid (Day et al. 2003; Duncan et al. 1997; Howley et al. 1995). Robergs (2001) suggested that this lack of research-supported guidelines for $\dot{V}O_{2\,max}$ determination may contribute to errors in measurement and interpretation. For example, errors in $\dot{V}O_{2\,max}$ determination may result in errors in exercise prescription based on the $\dot{V}O_{2\,max}$ value, or an incorrect decision as to whether an athlete's $\dot{V}O_{2\,max}$ has changed in response to a training intervention. Further empirical research is therefore important in establishing valid and robust criteria for $\dot{V}O_{2\,max}$ determination.

Thoden (1991) recommended that athletes should perform a verification phase following the incremental phase of a $\dot{V}O_{2\,max}$ test. The verification phase consists of 5–15 min recovery followed by a constant speed run to exhaustion that is a speed 1 stage higher than the last completed stage in the incremental phase. A peak $\dot{V}O_2$ in the verification phase that is similar (within the tolerance of measurement error) or lower than the $\dot{V}O_{2\,max}$ value attained in the incremental phase would provide additional confirmation that a true $\dot{V}O_{2\,max}$ has been elicited. The verification phase is conceptually similar to the plateau criterion when the criterion is applied to discontinuous incremental test protocols, as first described by Taylor et al. (1955).

To the best of our knowledge, the utility of the verification phase in $\dot{V}O_{2\,max}$ determination has not been reported in the literature. The main aim of the present study was to compare the maximum $\dot{V}O_{2\,max}$ values elicited by competitive distance runners during incremental and verification phases of a $\dot{V}O_{2\,max}$ treadmill running test. This was to assess the utility of the verification phase for increasing confidence in identifying that a true $\dot{V}O_{2\,max}$ has been attained. A second aim was to compare the maximum heart rate values elicited during the incremental and verification phases under the premise that similar values (within the tolerance of measurement error) would increase confidence that a maximum effort has been given. We hypothesized that maximum $\dot{V}O_2$ and heart rate values elicited in the verification phase would be sufficiently similar to those elicited in the incremental phase, as well as sufficiently reproducible for the verification procedure to be of practical use in the evaluation of the quality of a $\dot{V}O_{2\,max}$ test.

Materials and methods

Subjects

Sixteen male middle- and long-distance runners volunteered to participate in the study. The study was approved by the university departmental ethics committee and all subjects provided written informed consent after having the experimental procedures explained to them verbally and in writing. Subjects were recruited from local athletics clubs and were apparently healthy, not taking any medications, were non-smokers, and had the following characteristics (mean ± SD): age, 38.7 ± 7.5 y; height, 1.76 ± 0.06 m; body mass, 71.1 ± 8.1 kg; and relative $\dot{V}O_{2\,max}$, 57.1 ± 7.2 mL·kg^{-1}·min^{-1}.

Procedures

Subjects visited the laboratory on 3 separate days with each visit separated by at least 48 h and no more than 8 days separating the last 2 visits. The first visit was to habituate subjects with equipment and procedures and visits 2 and 3 involved performing identical tests to determine $\dot{V}O_{2\,max}$. Tests were performed on a motorised treadmill (Ergo ELG 55, Woodway GmbH, Steinackerstrasse, Germany) set at a 1% gradient to reflect the $\dot{V}O_2$ response to level outdoor running (Jones and Doust 1996). This allows for the determination of the velocity at $\dot{V}O_{2\,max}$ ($v\dot{V}O_{2\,max}$) used to prescribe training speeds for distance runners (Billat et al. 1999). Although incline-incremented treadmill tests have sometimes been found to elicit higher $\dot{V}O_{2\,max}$ values (Taylor et al. 1955; Hermansen and Saltin 1969), speed-incremented tests for runners who predominantly train and compete on relatively level surfaces should improve test validity, since testing is more useful with greater specificity (Dal Monte et al. 1974). Expired air was analyzed breath by breath using an automated open-circuit gas analyzis system (Quark b^2, Cosmed Srl, Rome, Italy). The gas analyzers were calibrated immediately before each test using ambient air (assumed to contain 20.94% O_2 and 0.03% CO_2; Carpenter 1937), and certified standard gases containing 16.0% ± 0.02% O_2 and 5.0% ± 0.02% CO_2 (Cryoservice Ltd, Worcester, UK). The turbine flow meter used for the determination of minute ventilation was calibrated with a 3 L syringe (Cosmed Srl) immediately before each test. The flow meter was inserted into a face mask with a combined functional dead space of 65 mL. Heart rate was continuously measured with a heart rate monitor (model T41, Polar Electro Oy, Kempele, Finland) with the receiver integrated into the Cosmed Quark b^2 metabolic cart. Heart rate and metabolic data were processed using Cosmed data management software®.

Determination of $\dot{V}O_{2\,max}$

Each subject performed a 5-min warm-up at the same speed as the first stage of the incremental test followed by 5 min of light static stretching. Treadmill speed was then increased by 1 km·h^{-1}·min^{-1} for the first 5 increments and by 0.5 km·h^{-1}·min^{-1} thereafter, until the subject terminated the test due to volitional exhaustion. The incremental phase was designed to elicit exhaustion within 8–17 min (Buchfuhrer et al. 1983). An appropriate initial treadmill speed was estimated by taking into account the initial speed and time to exhaustion in the incremental test during habituation (Howley et al. 1995). After the incremental phase the subject walked at 5 km·h^{-1} for 10 min and subsequently performed a verification phase. The verification phase consisted of running to volitional exhaustion at a speed (range 15.0–21.5 km·h^{-1}) 0.5 km·h^{-1} higher than that

reached in the last completed stage of the incremental phase (range 14.5–21.0 km·h^{-1}).

Breath-by-breath data were 30 s stationary retrograde time averaged (Billat et al. 2001; Dupont and Berthoin 2004) and the highest averaged $\dot{V}O_2$ value attained during the incremental phase was regarded as $\dot{V}O_{2\,max}$. Heart rate data were reduced to 5 s stationary retrograde time-average intervals and the highest averaged value attained during the incremental phase was regarded as HR_{max} (Millet et al. 2003). The primary criterion for identifying that a "true" $\dot{V}O_{2\,max}$ had been elicited during the incremental phase was a plateau in $\dot{V}O_2$, identified by an increase in treadmill speed with no further increase in $\dot{V}O_2$ (Howley et al. 1995). No increase or a drop in $\dot{V}O_2$ in response to an increase in workload during an incremental test has been termed an "absolute plateau" (Froelicher et al. 1974). In determining if a plateau had occurred, only complete 30 s $\dot{V}O_2$ averages were used in instances where the subject did not complete the last stage. Secondary criteria for establishing whether a maximum effort had been given were a maximum respiratory exchange ratio (RER_{max}) ≥1.10 (Howley et al. 1995) and a HR_{max} within 10 beats·min^{-1} of the age-predicted maximum (220 – age; Howley et al. 1995). The highest averaged $\dot{V}O_2$ value attained during the verification phase was regarded as $\dot{V}O_{2\,verif}$ and the highest averaged heart rate value as HR_{verif}. A graphical example of the $\dot{V}O_2$ and heart rate responses of a single subject to the incremental and verification phases of the $\dot{V}O_{2\,max}$ test is shown in Fig. 1. The $\dot{V}O_{2\,max}$ was verified when the $\dot{V}O_{2\,verif}$ was not more than 2% higher than $\dot{V}O_{2\,max}$. A HR_{verif} within 2 beats·min^{-1} of HR_{max} verified that a maximum effort had been given. The 2% criterion for $\dot{V}O_{2\,max}$ verification was based on the error in $\dot{V}O_2$ determination derived from the turbine flow meter measurement error reported by the manufacturer. The technical error of 0.01% and 0.03% for the O_2 and CO_2 analyzers, respectively, reported by the manufacturer, were ignored since this amount of error has negligible effect on the calculation of $\dot{V}O_2$ within the physiological range. This measurement error should not be confused with the greater variation in $\dot{V}O_{2\,max}$ determination derived predominantly from day-to-day biological variation (Katch et al. 1982). The 2 beats·min^{-1} criterion for HR_{max} verification allowed for any small amount of error in heart rate determination due to technical error, or variation caused by natural physiological causes (Maritz et al. 1961).

Analyses

Deviations from a normal distribution for all variables were tested using the Shapiro–Wilk test and were not significant ($p > 0.05$). Trial 1 and 2 differences and incremental and verification differences were analyzed using 2-tailed paired *t* tests. Test–retest reproducibility was analyzed using the repeated measures coefficient of variation, calculated by dividing the standard deviation of the differences by the square root of 2 and dividing the answer by the grand mean, and was expressed as a percentage. The α level for tests of significance was set a priori at 0.05. Analyses were completed using SPSS® for Windows software (release 11.5.0; SPSS Inc., Chicago, Ill.).

Results

Mean responses and within-subject variation for the duplicate $\dot{V}O_{2\,max}$ treadmill running tests for all 16 athletes are shown in Table 1. All between-trial mean differences were not significant, except the mean HR_{verif} elicited in trial 2 was significantly lower than in trial 1. Test–retest differences for time to exhaustion (t_{lim}) in the verification phase were not reported because 4 subjects ran the verification phases at different speeds (because the number of stages completed in the incremental phases was different). Incremental and verification phase mean differences for criterion variables are shown in Table 2. The mean HR_{max} was significantly higher than the mean HR_{verif} in trial 2, whereas RER_{max} was significantly higher than RER_{verif} in both trials 1 and 2. Figures 2 and 3 show scatter plots of $\dot{V}O_{2\,max}$ against $\dot{V}O_{2\,verif}$ and HR_{max} against HR_{verif}, respectively. Figure 3 shows that HR_{verif} had a tendency to be lower than HR_{max}, indicated by 19 of the plots being lower than the line of identity compared with only 4 above the line (all plots would lay on the line of identity if HR_{max} and HR_{verif} were identical for all tests). The distribution of the $\dot{V}O_{2\,max} - \dot{V}O_{2\,verif}$ differences for trial 1 are shown in Fig. 4. This figure highlights that the differences are approximately normally distributed with most of the errors clustered around the mean difference (e.g., 10 of the $\dot{V}O_{2\,max} - \dot{V}O_{2\,verif}$ differences were ≤ 75 mL·min^{-1}). Table 3 shows the number of subjects that satisfied primary, secondary, and verification criteria. The number of subjects that satisfied the heart rate and respiratory exchange ratio criteria during the incremental test phase and the $\dot{V}O_2$ and heart rate criteria in the verification phase were similar. The number of subjects that satisfied the $\dot{V}O_2$ plateau criterion was substantially less than the other 4 criteria. The number of subjects that satisfied each criterion was similar for trials 1 and 2, indicating that no meaningful bias in the number of subjects that satisfied each criterion occurred during repeated testing.

Discussion

The main finding of this study is that a verification phase may provide useful additional information for identifying that a "true" $\dot{V}O_{2\,max}$ has been elicited during an incremental test, particularly in view of the criticisms directed at existing criteria for $\dot{V}O_{2\,max}$ determination (Day et al. 2003; Duncan et al. 1997; Howley et al. 1995). The verification phase is conceptually similar to identification of a $\dot{V}O_2$ plateau during a discontinuous test protocol, originally described by Taylor et al. (1955), but has the advantage of not requiring multiple visits to the laboratory. Although the plateau criterion has been applied to continuous test protocols, the validity of this practice has been questioned (Howley et al. 1995). In the present study, only 16 tests satisfied the plateau criterion compared with 26 that satisfied the $\dot{V}O_{2\,max}$ verification criterion. This suggests that the verification criterion is the more robust of the 2 criteria when using a continuous test protocol. The repeated measures coefficient of variation of 3.9% for $\dot{V}O_{2\,verif}$ was similar to the 3.5% for $\dot{V}O_{2\,max}$ and indicates that $\dot{V}O_{2\,verif}$ is sufficiently reproducible to be of practical use in $\dot{V}O_{2\,max}$ verification. Katch et al. (1982) estimated that 90% of the day-to-

Fig. 1. The heart rate and $\dot{V}O_2$ response to the $\dot{V}O_{2\,max}$ test (incremental, recovery, and verification phases) for a typical subject. The $HR_{max} - HR_{verif}$ difference was 1 beat·min^{-1} and the $\dot{V}O_{2\,max} - \dot{V}O_{2\,verif}$ difference was 11 mL·min^{-1}, therefore providing a high degree of confidence that $\dot{V}O_{2\,max}$ and HR_{max} were attained in the incremental phase.

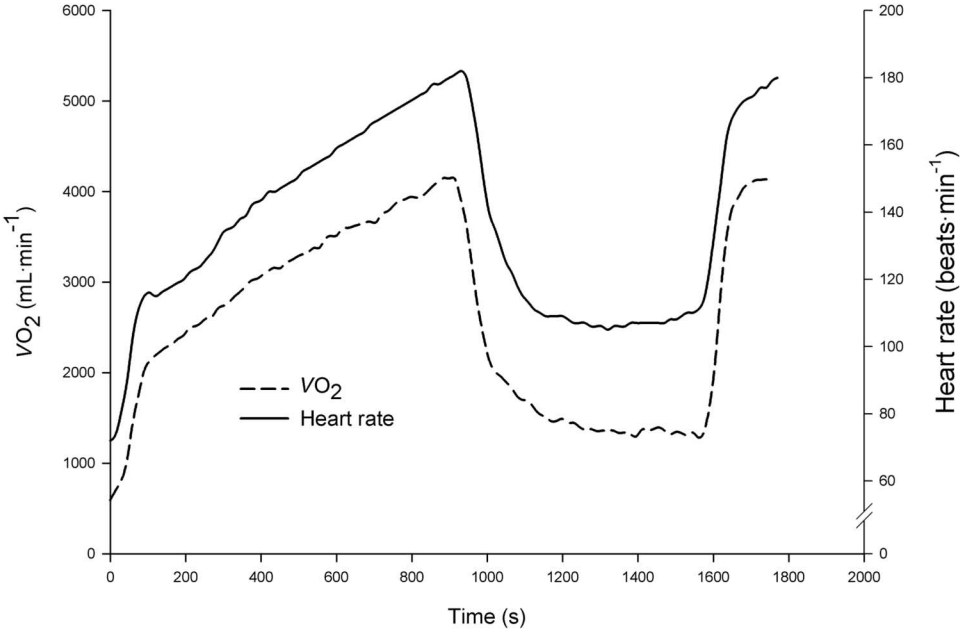


Table 1. Responses to the incremental and verification phases of the repeated $\dot{V}O_{2\,max}$ test (n = 16).

	Incremental phase t_{lim} (s)	Verification phase t_{lim} (s)[a]	$\dot{V}O_{2\,max}$ (mL·min^{-1})	$\dot{V}O_{2\,verif}$ (mL·min^{-1})	HR_{max} (beats·min^{-1})	HR_{verif} (beats·min^{-1})	RER_{max}	RER_{verif}
Trial 1								
Mean	698	165	4041	3994	178.6	177.5	1.12	1.07
SD	114	37	455	447	10.2	9.3	0.05	0.06
Range	541–924	103–235	3085–4610	3311–4704	163–193	165–192	1.01–1.21	0.98–1.18
Trial 2								
Mean	710	172	4010	4029	177.7	175.8	1.11	1.08
SD	94	34	379	432	10.6	10.7	0.05	0.05
Range	551–899	105–222	3257–4580	3317–5037	160–192	157–192	1.02–1.17	1.01–1.16
Trial 1 – trial 2 differences								
Mean diff	12	—	–31	35	–0.9	–1.7*	–0.01	0.01
95% CI	–10, 34	—	–127,65	–83 152	–2.5,0.8	–3.3,-0.1	–0.03,0.01	–0.01,0.03
S_d	41.6	—	180.0	220.9	3.1	3.0	0.04	0.04
CV%	3.9	—	3.5	3.9	1.2	1.2	2.4	2.7

Note: t_{lim}, time to exhaustion; $\dot{V}O_{2\,max}$, highest averaged $\dot{V}O_2$ value attained in the incremental phase; $\dot{V}O_{2\,verif}$ highest averaged $\dot{V}O_2$ value attained in the verification phase; HR_{max}, highest averaged heart rate value attained in the incremental phase; HR_{verif}, highest averaged heart rate value attained in the verification phase; RER_{max}, highest averaged respiratory exchange ratio value attained in the incremental phase; RER_{verif}, highest averaged respiratory exchange ratio value attained in the verification phase; SD, standard deviation of the mean; diff, difference; 95% CI, 95% confidence interval for the mean difference; S_d, standard deviation of the differences; CV%, repeated measures coefficient of variation expressed as a percentage. Asterisk indicates $p < 0.05$.

[a]Four subjects ran the test–retest verification phases at different speeds because the number of stages completed in the incremental phase was different; trial 1 – trial 2 differences are therefore not reported.

day variation in $\dot{V}O_2$ max was due to biological variation and the remaining 10% was due to technical error. This should also be true for the variation in $\dot{V}O_{2\,verif}$ although further research is required to confirm this assumption. Since most of the day-to-day variation in $\dot{V}O_{2\,max}$ and $\dot{V}O_{2\,verif}$ is probably related to day-to-day biological variation, strict pre-test procedures are recommended to minimize this source of variation.

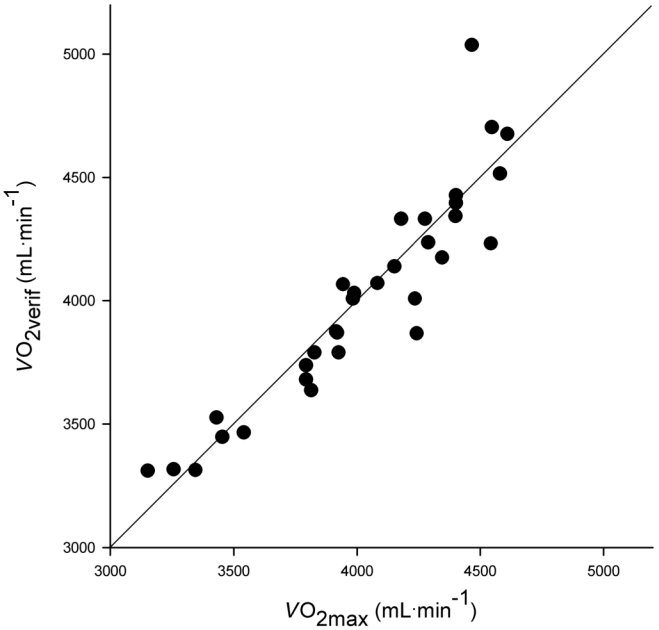
A potential limitation to the verification phase is that the $\dot{V}O_{2\,verif}$ may be lower than $\dot{V}O_{2\,max}$ because the $\dot{V}O_2$ has not had time to reach its maximum before volitional exhaustion occurs. This is probably the rationale for the recommendation made by Thoden (1991), i.e., that if the verification phase lasts less than 3 min, the subject should perform the verification phase at the same or 1 stage below the last completed stage in the incremental phase if retested. All 7 tests in the present study that exhibited $\dot{V}O_{2\,verif}$ values that were over 100 mL·min^{-1} (≥ 3%) lower than $\dot{V}O_{2\,max}$ had verification t_{lim} values that were lower than the mean value of 2 min 49 s (SD 35 s; range 103 to 235 s). In fact, only 13 of the 32 verification phases lasted ≥3 min, providing support that the verification phase protocol may require modification to improve its utility. The verification phase involved 10 min of walking at 5 km·h^{-1} followed by a rapid accelera-

Table 2. Incremental and verification phase differences in the $\dot{V}O_{2\ max}$ test (n = 16).

	$\dot{V}O_{2\ max} - \dot{V}O_{2\ verif}$ (mL·min^{-1})	$HR_{max} - HR_{verif}$ (beats·min^{-1})	$RER_{max} - RER_{verif}$
Trial 1			
Mean diff	–47	–1.1	–0.06*
95% CI	–122, 29	–2.2, 0.1	–0.08, –0.03
S_d	142	2.1	0.04
Trial 2			
Mean diff	19	–1.9*	–0.04*
95% CI	–79, 116	–2.8, –0.9	–0.06, –0.01
S_d	182	1.7	0.04

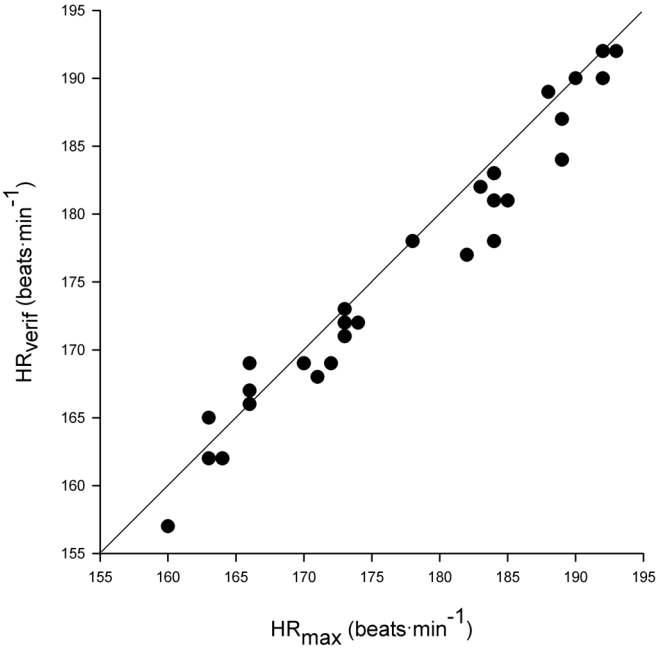
Note: See footnote to Table 1 for an explanation of abbreviations. Asterisk indicates $p < 0.05$.

Fig. 2. Comparison of $\dot{V}O_{2\ max}$ and $\dot{V}O_{2\ verif}$ for all 32 $\dot{V}O_{2\ max}$ tests. The diagonal line is the line of identity.



tion to a speed 0.5 km·h^{-1} higher than that reached in the last completed stage of the incremental phase (mean verification phase speed 17.7 ± 1.5 km·h^{-1}). This large and rapid change in treadmill speed may have induced a rapid accumulation of intramuscular lactate (Duncan et al. 1997); in some people, this may have caused volitional exhaustion before $\dot{V}O_{2\ max}$ was attained (which may be more prevalent in individuals with relatively slow $\dot{V}O_2$ kinetics). A 2 min run at about 60% $\dot{V}O_{2\ max}$ immediately preceding the verification phase might have improved the verification procedure by allowing $\dot{V}O_2$ to reach a higher percentage of $\dot{V}O_{2\ max}$ before the start of a rapid accumulation of intramuscular lactate. The significantly lower RER_{max} in the verification phase compared with the incremental phase would suggest lower levels of lactate accumulation (Issekutz and Rodahl 1961), possibly due to decreased carbohydrate metabolism and an increase in lipid metabolism. Increased lipid metabolism may be related to a decrease in skeletal muscle glycogen and plasma insulin concentration resulting from the warm-up, incremental, and recovery phases (Holloszy et al.

Fig. 3. Comparison of HR_{max} and HR_{verif} for all 32 $\dot{V}O_{2\ max}$ tests. The diagonal line is the line of identity.



1998). However, an alternative explanation is that the lactate gradient between the muscle and the blood may have been larger during the verification phase owing to the relatively short duration (mean 2.8 ± 0.6 min) of this test phase. The lower blood lactate concentration would decrease the production of non-metabolic CO_2 and therefore the RER (Issekutz and Rodahl 1961). Differences in pulmonary ventilation between the incremental and verification phases could also explain the differences in RER_{max} values. A delay in the ventilatory response due to the relatively short duration of the verification phase may have attenuated $\dot{V}CO_2$ and therefore the RER.

Previous studies have reported higher peak $\dot{V}O_2$ values during supra-critical velocity constant work rate exercise, as well as during intermittent maximal exercise, than during the incremental test used to determine $\dot{V}O_{2\ max}$ (Billat et al. 2000, 2001; Blondel et al. 2001; Demarie et al. 2000; Hill et al. 1997). These studies support previous findings that a true $\dot{V}O_{2\ max}$ may not always be elicited in some $\dot{V}O_{2\ max}$ test protocols (Buchfuhrer et al. 1983). There may also be inter-individual variation in the type of test protocol that elicits $\dot{V}O_{2\ max}$. Four subjects in the present study attained a $\dot{V}O_2$ value in the verification phase that was more than 150 mL·min^{-1} higher (≥3.5%) than in the incremental phase. In subjects who demonstrate a $\dot{V}O_{2\ verif}$ greater than 2% higher than $\dot{V}O_{2\ max}$, it is unclear what decision to make, particularly when considering that the 4 runners in the present study who attained ≥3.5% higher $\dot{V}O_{2\ verif}$ values all demonstrated an absolute $\dot{V}O_2$ plateau in the incremental phase. The verification phase value, or a mean of the incremental and verification values, could be regarded as $\dot{V}O_{2\ max}$ in this instance. When using a verification phase in experimental research, if a significant systematic increase occurs between $\dot{V}O_{2\ max}$ and $\dot{V}O_{2\ verif}$ the investigator should consider that the incremental phase protocol was inadequate in

Fig. 4. Bland–Altman plot showing trial 1 individual $\dot{V}O_{2\ max}$ – $\dot{V}O_{2\ verif}$ differences plotted against their individual mean values (n = 16). The horizontal dashed lines represent the 95% limits of agreement. The solid horizontal line is the line of identity. SD, standard deviation.

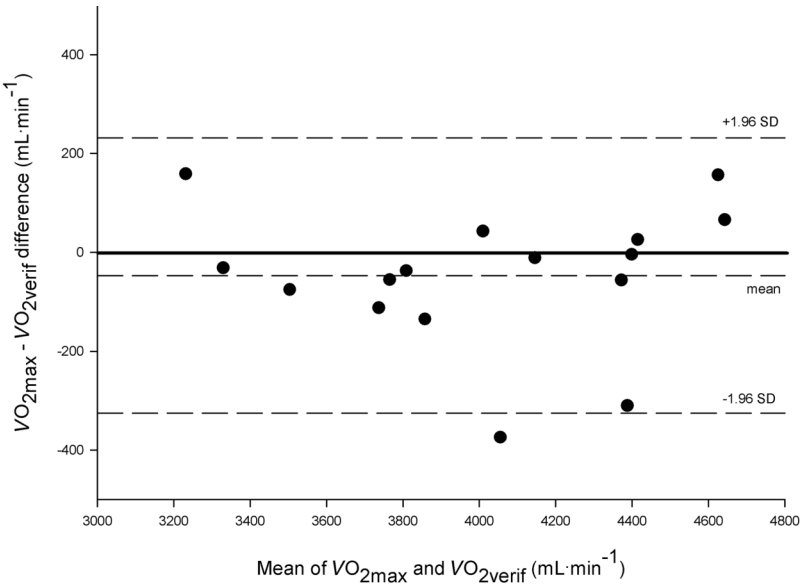


Table 3. Number of subjects who satisfied the primary, secondary and verification criteria for $\dot{V}O_{2\ max}$ determination (n = 16; total number of tests = 32).

	Absolute $\dot{V}O_2$ plateau	HR within 10 beats·min^{-1} age-predicted HR_{max}	RER_{max} ≥1.10	$\dot{V}O_{2\ max}$ verification[a]	HR_{max} verification[b]
Trial 1	8	13	13	14	12
Trial 2	8	12	11	12	11
Both trials	5	12	11	10	10
One trial	6	1	2	6	3
Neither trial	5	3	3	0	3

Note: HR, heart rate. See footnote to Table 1 for an explanation of all other abbreviations.

[a] $\dot{V}O_{2\ verif}$ no more than 2% higher than $\dot{V}O_{2\ max}$.

[b] HR_{verif} within 2 beats·min^{-1} of HR_{max}.

eliciting a true $\dot{V}O_{2\ max}$ in at least some, if not all, of the subjects.

In the present study of relatively well-trained distance runners, an absolute $\dot{V}O_2$ plateau was identified in 50% of the incremental phases of the $\dot{V}O_{2\ max}$ tests. Several authors have suggested that the absence of a $\dot{V}O_2$ plateau does not provide evidence that a subject has not elicited a "true" $\dot{V}O_{2\ max}$ (Day et al. 2003; Duncan et al. 1997). The present study supports this view, as 5 of the subjects who did not demonstrate a $\dot{V}O_2$ plateau attained almost identical $\dot{V}O_{2\ max}$ and $\dot{V}O_{2\ verif}$ values. Further support is provided by the observation that in the 6 subjects who demonstrated a plateau in only 1 $\dot{V}O_{2\ max}$ test, the mean $\dot{V}O_{2\ max}$ value for the tests that demonstrated a plateau was very similar (32 mL·min^{-1} difference) to the mean value of the tests where no plateau was evident. This observation is consistent with that reported by Katch et al. (1982).

In relation to $\dot{V}O_{2\ max}$ determination, the secondary criterion based on age-predicted HR_{max} has been criticised because of the large inter-individual variation in HR_{max} for any particular age (Tanaka et al. 2001). Furthermore, the attainment of the heart rate criterion may be more difficult in endurance-trained individuals, since endurance training has been associated with a decrease in HR_{max} (Scheuer and Tipton 1977). The HR_{max} verification criterion is not affected by either of these limitations and may therefore prove to be a more valid criterion. Maximal heart rate verification may also be useful when using the HR_{max} value as the basis for training intensity prescription. Since it is improbable that a subject could give 2 identical submaximal efforts in 2 different exercise protocols (Day et al. 2003), similar maximal heart rates in the incremental and verification phases of a $\dot{V}O_{2\ max}$ test (within the tolerance of acceptable measurement error; Howley et al. 1995), would provide increased confidence that the subject gave a maximal effort. Of the 32 tests conducted in the present study 23 satisfied the HR_{max} verification criterion. However, the mean HR_{verif} was lower than the mean HR_{max} in both trials (Table 2); and although the mean bias was small, this bias could substantially reduce the utility of HR_{max} verification since the verification criteria was only 2 beats·min^{-1}. This provides further support that the verification phase protocol was not always adequate in eliciting maximal physiological values and may need modifying to improve its utility.

A potential limitation to the verification phase is deciding

on appropriate criteria to conclude that the $\dot{V}O_{2\,max}$ or HR_{max} has been verified. Since the determination of physiological measures is associated with some degree of error (Atkinson and Nevill 2001), verification criteria that are too conservative would result in valid verification values being rejected. More liberal verification criteria would increase the probability that (by chance) verification has occurred during 2 submaximal efforts. Further work is therefore required to investigate whether there are more appropriate verification criteria than those used in the present study to control for these 2 types of error.

A methodological limitation in the present study may have been the continuous measurement of gas exchange during the incremental, recovery, and verification phases (mean combined time 24.4 ± 2.0 min). In addition to the potential for gas analyzer drift during this time period that may introduce increased technical error in $\dot{V}O_2$ determination, subjects also probably experienced increased physical discomfort. An increase in respiratory stress and perceived exertion may have caused the subject to prematurely terminate the verification phase (Noakes et al. 2005) thereby reducing its efficacy. Although the gas analyzers were calibrated within 10 min after the termination of the verification phase to check analyzer functionality, to minimize analyzer drift and subject discomfort during future verification procedures we recommend the face mask or mouth piece should be removed during the recovery phase and the gas analyzers re-calibrated prior to the start of the verification phase.

In conclusion, to the best of our knowledge this is the first study to investigate the utility of the verification phase in the determination of $\dot{V}O_{2\,max}$. Our results indicate that a verification phase may prove useful for establishing that a subject has attained a true $\dot{V}O_{2\,max}$ and that a maximum effort has been given; however, an improved verification protocol than that used in the present study is probably required. Further research should therefore investigate whether different verification protocols and criteria than those used in this study could improve the utility of the verification phase. The question of whether the verification phase is a useful tool in the $\dot{V}O_{2\,max}$ testing of other target populations, such as untrained individuals, also needs to be addressed. If further research confirms the utility of the verification phase it then needs to be decided how this additional information will be combined with the existing criteria for evaluating the results of a $\dot{V}O_{2\,max}$ test.

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