SWACSM Abstract

Efficacy of a Regression Method to Confirm VO_2max in Middle-Aged and Older Adults: A Pilot Study

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ABSTRACT

Verification testing following a maximal graded exercise test (GXT) has been shown to be effective at indicating whether VO_2max was attained for middle-aged and older adults but performing two maximal efforts in a single day may not be practical or possible for certain individuals. **PURPOSE**: To evaluate the efficacy of a regression method for identifying a VO_2 plateau in order to confirm the attainment of VO_2max. **METHODS**: Twenty-one recreationally active (VO_2max: 21.8-50.3 ml/kg/min) middle-aged and older (46-76 yrs.) men (n=11) and women (n=10) completed an individualized ramp GXT on the cycle ergometer, and one hour later, a verification protocol at 105% of their maximal work rate (WR) achieved during the GXT. Verification criterion was met if the difference between the highest VO_2 during the verification was ≤2% greater than the VO_2max achieved during the GXT. VO_2 plateau was identified by least-squares regression analysis of the 4 minutes immediately prior to the last 2 minutes of the VO_2-WR curve. Modelled VO_2max was extrapolated using the VO_2-WR regression equation and the maximum WR achieved during the GXT. If the difference between modelled and actual VO_2max was >50% of the slope for the linear portion of the VO_2-WR relationship relative to the assigned protocol, then a plateau was observed. McNemar's test of marginal homogeneity was used to detect differences in the proportion of paired data of individuals' attainment of VO_2max criteria. **RESULTS**: Of the 21 participants,15 (71.4%) met the verification criterion while 6 (28.6%) did not, compared to the regression method where 16 (76.2%) achieved the regression criterion while 5 (23.8%) did not. McNemar's test revealed no significant difference between participants' ability to achieve the regression and verification criteria ($X^2(1)=0$, $p=.999$). **CONCLUSION**: The regression method used in this study may be an effective strategy for determining VO_2 plateau and confirming that VO_2max was attained during a GXT with middle-aged and older adults on a cycle ergometer. This time-efficient regression method is comparable with the verification criterion but does not require a second maximal test, which may be advantageous for those where the verification trial may not be practical.

Introduction

The identification and confirmation of 'true' maximal oxygen uptake (VO_2max) achieved during a graded exercise test (GXT) has been the source of debate since the seminal works of A.V. Hill and colleagues (7). The most common indicator of VO_2max is a plateau in VO_2 despite an increase in exercise intensity (1). Despite its prevalence in research, there is no agreed upon 'gold standard' for what constitutes a plateau (8,11). The most cited VO_2 plateau criterion was proposed by Taylor et al. (16) and is a difference in VO_2 of ≤2.1 ml/kg/min or approximately ≤150 ml/min as a participant nears exhaustion (11). Achieving this criterion is highly variable (2) and has been demonstrated to be influenced by age, protocol, modality, and the methodology used in data analysis (3). The inclusion of a verification bout following a GXT that requires participants to exercise at a greater absolute work rate than that achieved during the GXT helps to avoid issues concerning the 150 ml/min VO_2 plateau criterion (10). A higher VO_2 observed when exercising at a greater work rate (WR), indicates that the highest VO_2 during the GXT was not a 'true' maximal value (12). While this method has been demonstrated to be an effective assessment to indicate that VO_2max was attained with middle-aged and older adults (5,6), performing two maximal efforts in a single day may not be comfortable, practical, or possible for certain populations.

A technique to confirm VO_2max that does not require a second maximal test is a least-squares linear regression analysis of the slope of the VO_2-WR relationship (9,13). By modelling the rate at which VO_2 increases during the linear portion of an individual's VO_2-WR relationship relative to the protocol used during the GXT and assessing the difference between a modeled and predicted VO_2max values, a plateau can be identified that is individualized to each participant's VO_2 kinetics (9,12). This regression method has only been used in young (27 ± 4 yrs.) adult males (13) or a cohort of very fit male cyclists and runners with an average age of 37 yrs. (9). Importantly, previous researchers have demonstrated that advancing age alters VO_2 kinetics during exercise (15). Therefore, the efficacy of this criterion to confirm attainment of VO_2max for middle-aged and older adults is unknown. Accordingly, expanding on the work of Poole et al. (13) and Midgley et al. (9), the present study seeks to evaluate the efficacy of a regression strategy for identifying a VO_2 plateau and therefore confirming that VO_2max was attained in a sample of middle-aged and older adults on the cycle ergometer compared to the verification criterion.

Methods

Participants

Twenty-four recreationally active (≥150 minutes of moderate to vigorous intensity aerobic activity per week for one or more years) middle-aged and older men (n=12) and women (n=12) participated in the parent study in which the maximal exertion data were recorded (6). The study was conducted in Albuquerque, NM at an altitude of 1,585 m and at which participants had resided for at least 6 months prior to testing. All participants provided written informed consent before enrolling in the study and all procedures were approved by the local Institutional Review Board for human subjects research.

Experimental Design

Participants completed a maximal GXT and a verification bout on an electronically braked cycle ergometer (Excalibur Sport, Corval Lode B. V., Lode Medical Technology, Groningen, Netherlands). Testing was completed in a single day and tests were separated by 60 minutes of seated recovery. Participants were asked to refrain from caffeine (12 hours), heavy exercise and alcohol (24 hours) prior to testing. Participants performed a 5-minute warm-up on the cycle ergometer at a self-selected exercise intensity. After the warm-up, subjects donned a mouthpiece (Hans Rudolph Inc., Kansas City, MO) and nose clip. Gas exchange data were analyzed using a metabolic cart (Parvomedics TrueOne 2400, Sandy, UT). The metabolic cart was calibrated prior to each test according to the manufacturer's instructions. Participants began an individualized GXT designed to elicit volitional exhaustion within 8-12 min (17). Individualized ramp protocols (10-30 watts/min) were selected based on sex, body mass, and activity level. Expired gases were collected for the verification protocol in the same manner as was done during the GXT. The verification protocol consisted of exercising for 2 minutes at 50%, 1 minute at 70%, and until volitional exhaustion at 105% of the maximal work rate achieved during the GXT (10). Upon verification trial termination, participants engaged in an active recovery for five minutes.

Data Processing

Data were time-averaged using retrograde 30s intervals; the highest averaged 30s value for VO_2 was classified as VO_2max (10). VO_2max was confirmed using a verification trial. A 2% criterion for measurement error between VO_2max and the highest VO_2 during the verification trial (VO_2verfi) was used. This criterion was based on the measurement error claimed by the manufacturer (ParvoMedics) when assessing flow via a pneumotachometer (Hans Rudolph Inc., Kansas City, MO) (4). The verification

criterion was met if the difference between the VO_2verfi was ≤2% greater than the VO_2max achieved during the GXT (10). A VO_2 plateau was identified by least-squares regression analysis of the 4 minutes immediately prior to the last 2 minutes of the VO_2-WR (30s average values) curve as this was determined to best represent the linear portion of the VO_2-WR relationship (Figure 1) (9). The strength of this linear relationship was assessed using the coefficient of determination (R^2). A modelled VO_2max (mVO_2max) was extrapolated using the VO_2-WR regression equation and the maximum WR achieved during the GXT. To account for the influence of the protocol used during maximal testing on VO_2 kinetics, the slope was multiplied by the WR of the protocol. If the difference between the modelled and actual VO_2max was >50% of the slope for linear portion of the VO_2-WR relationship relative to the assigned protocol, then a plateau was observed (9). Furthermore, individual VO_2-WR responses were assessed using the 95% confidence interval (CI) of the regression slope at mVO_2max, so that if VO_2max was above the 95%CI, then this was evidence of an accelerated or nonlinear VO_2 response. If VO_2max was within the 95%CI this was a linear VO_2 response, and if VO_2max was below the 95%CI, then this confirmed that a plateau in VO_2 occurred (12,13).

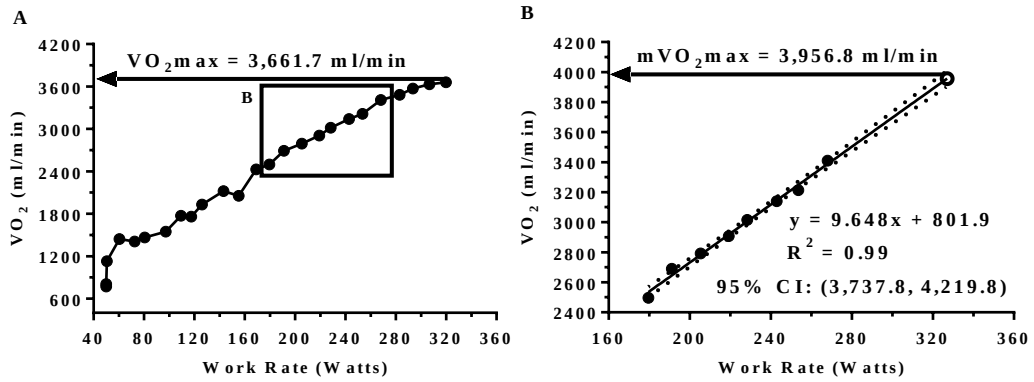

Figure 1. Example of a plateau in VO_2 identified through least-squares regression analysis of the linear VO_2 kinetics during a 25 watts/min ramp protocol (n=1). A) Raw data of the VO_2-WR relationship using 30s retrograde values during a graded exercise test. B) Least-squares regression of the linear VO_2 kinetics and modeled VO_2max (mVO_2max) extrapolated from maximum work rate achieved during the graded exercise test (open circle). VO_2 kinetics relative to the protocol used during maximal testing was determined to be 241.2 ml/min for every 25 watts increase as calculated by the product of the slope (9.648 ml/min) and protocol (25 watts/min). The difference between the modelled and actual VO_2max was 295.1 ml/min, which is >50% of 241.2 ml/min, therefore, a plateau was observed. VO_2max also fell below the 95%CI of mVO_2max confirming that a plateau in VO_2 occurred.

Statistical Analysis

Individual responses for the verification and regression methods were compared to confirm VO_2max attainment. McNemar's tests of marginal homogeneity was used to detect differences in the proportion of paired data of individuals' attainment of VO_2max criteria via R version 4.0.2 (R Core Team, 2021). The least-squares regression technique was performed via Prism version 6 (GraphPad Software Inc., La Jolla, CA).

Results

Due to technical difficulties with the metabolic cart, data from two of the women could not be used. Additionally, case diagnostics identified a 47-year-old man with a VO_2max of 47.1 ml/kg/min as an influential outlier by having a large Cook's D relative to the rest of the data set. The analysis after the removal of this participant will be presented. Table 1 shows the participant demographics and physiological data for the remaining men (n=11) and women (n=10) that were included in data analysis. The slopes of the linear VO_2-WR relationship during the GXT ranged from 69.2 to 331.2 ml/watt/min with an average of 178.7 ± 63.3 ml/watt/min. The R^2 for the regression models ranged from .85 to .99 with an average of .96 ± .04. The average upper and lower bounds of the 95%CI of mVO_2max were 2,351.9 ± 842.7 and 2,704.5 ± 961.4 ml/min, respectively.

Table 1. Participant characteristics (n=21)

	Mean ± SD	**Range**
Age (yrs.)	61.0 ± 8.1	46.0 – 76.0
Height (cm)	168.3 ± 9.8	145.7 – 184.0
Body mass (kg)	67.7 ± 14.0	49.7 – 103.2
VO_2max (ml//min)	2,371.4 ± 839.2	1,205.0 – 4,038.7
VO_2max (ml/kg/min)	34.7 ± 9.2	21.8 – 50.3
Work rate max (watts)	217.9 ± 74.1	86.0 – 364.0

The results of McNemar's test revealed no significant difference between participants' ability to achieve the regression and verification criteria ($X^2(1) = 0$, p =.999). Of the 21 participants included in the analysis, 15 (71.4%) met the verification criterion while 6 (28.6%) did not; compared to the regression method where 16 (76.2%) achieved the regression criterion while 5 (23.8%) did not. Individual VO_2 responses during the GXT revealed that; 9 participants (42.8%) had additional evidence of a plateau

since their VO_2max fell below the 95%CI of the mVO_2max, 12 participants (57.1%) demonstrated linear VO_2 kinetics as they were within the 95%CI, and no participants were above the 95%CI.

Discussion

The purpose of this study was to evaluate the efficacy of a regression strategy for identifying a VO_2 plateau that does not require a second bout of maximal exercise in a sample of middle-aged and older adults on the cycle ergometer. No significant difference was observed in the achievement rate between the regression model for assessing VO_2 plateau and the verification criterion for our sample, 76.2% vs 71.4%, respectively. Previous researchers have concluded that the regression method is comparable to the verification criterion with young adults (13) and the current study builds upon this finding by demonstrating its effectiveness in a sample of middle-aged and older adults of both sexes.

In this study, the verification bout was used as the reference method due to the wide variability in older adults exhibiting the ≤150 ml/min criteria for a plateau in VO_2 at the end of a GXT (14). Additionally, the verification criterion avoids relying on arbitrary cut-off values to indicate a physiological maximum has been achieved (13). In theory, those interpreting VO_2 data from a GXT could use the VO_2-WR relationship regression method to identify if a VO_2 plateau was achieved using the steps described above (Figure 1). A participant that meets both the regression and 95%CI criteria does not require a verification bout, thereby, not necessitating a second maximal test. On the other hand, if an individual met the regression criterion but their VO_2max was not below the 95%CI of the mVO_2max, then a verification bout is recommended to confirm VO_2max was attained during the GXT.

Conclusion

The results of this study suggest that using a regression method is an effective strategy for determining a VO_2 plateau in a sample of middle-aged and older adults exercising on a cycle ergometer. Furthermore, this method of confirming VO_2max is comparable with the verification criterion but does not require a second maximal test, which may be advantageous for those where the verification trial may not be comfortable, practical, or possible. We recommend that exercise physiologists and other health professionals consider using the regression method combined with the 95%CI of the modeled VO_2max criterion to confirm VO_2max during a GXT.

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