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A comparison of practical assessment methods to determine treadmill, cycle and elliptical ergometer $\text{VO}_{2\text{peak}}$

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Abstract

This investigation compared estimated and predicted peak oxygen consumption ($\text{VO}_{2\text{peak}}$) and maximal heart rate (HR_{max}) among the treadmill, cycle ergometer and elliptical ergometer. Seventeen women (mean $\pm$ SE: 21.9 $\pm$.3 yrs) exercised to exhaustion on all modalities. ACSM metabolic equations were used to estimate $\text{VO}_{2\text{peak}}$. Digital displays on the elliptical ergometer were used to estimate $\text{VO}_{2\text{peak}}$. Two individual linear regression methods were used to predict $\text{VO}_{2\text{peak}}$: 1) two steady state heart rate (HR) responses up to 85% of age-predicted HR_{max} , and 2) multiple steady state/non-steady state HR responses up to 85% of age-predicted HR_{max} . Estimated $\text{VO}_{2\text{peak}}$ for the treadmill (46.3 $\pm$ 1.3 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) and the elliptical ergometer (44.4 $\pm$ 1.0 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) did not differ. The cycle ergometer estimated $\text{VO}_{2\text{peak}}$ (36.5 $\pm$ 1.0 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) was lower ($p < .001$) than the estimated $\text{VO}_{2\text{peak}}$ values for the treadmill and elliptical ergometer. Elliptical ergometer $\text{VO}_{2\text{peak}}$ predicted from steady state (51.4 $\pm$.8 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) and steady state/non-steady state (50.3 $\pm$ 2.0 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) models were higher than estimated elliptical ergometer $\text{VO}_{2\text{peak}}$, $p < .01$. HR_{max} and estimates of $\text{VO}_{2\text{peak}}$ were similar between the treadmill and elliptical ergometer, thus cross-modal exercise prescriptions may be generated. The use of digital display estimates of submaximal oxygen uptake for the elliptical ergometer may not be an accurate method for predicting $\text{VO}_{2\text{peak}}$. Health-fitness professionals should use caution when utilizing submaximal elliptical ergometer digital display estimates to predict $\text{VO}_{2\text{peak}}$.

Keywords

ACSM equations; non-steady state exercise

INTRODUCTION

Maximal oxygen consumption may be determined through the use of various testing modalities that activate large amounts of muscle mass, provided both the intensity of effort and protocol duration are sufficient to maximize aerobic energy transfer (21). Uphill treadmill running has been regarded as the best overall mode for measuring maximal oxygen uptake due to the integration of a large volume of muscle mass leading to maximal aerobic

energy expenditure (24). Since the treadmill is considered the gold standard for the assessment of maximal oxygen uptake, it is widely utilized as the reference when comparing oxygen uptake (VO_2) measures obtained from other exercise modalities. Thus, for VO_2 obtained on other testing modalities to be considered maximal, it should be similar to values obtained during uphill treadmill running (17). Other modalities such as the Nordic Track cross-country ski ergometer (17), swimming (4), arm-crank ergometry (29), and elliptical ergometry (10) have been used to determine VO_2 during progressively incremented tests. Because there are a number of criteria that must be satisfied for determination of maximal oxygen uptake (e.g. change in VO_2 of $< 2.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ with increasing workload and $\text{RER} = 1.1$ at termination), peak oxygen consumption ($\text{VO}_{2\text{peak}}$) is often used to define the highest VO_2 achieved during an exercise test.

In recent years, the elliptical ergometer has become a popular exercise mode in health-fitness settings, in part due to it being a weight bearing modality that may not place as great a stress on joints and muscles as other weight bearing modes. Porcari et al. (26) found that the elliptical ergometer had less than half of the vertical ground reaction forces compared to treadmill running. Due to the lower stress placed on the body, the elliptical ergometer may provide a safe alternative to the treadmill in determining aerobic fitness in individuals with orthopedic limitations. Several studies have shown that the elliptical ergometer can be used for exercise testing in clinical and health-fitness settings (6, 7, 12) and may elicit similar physiological responses when compared to treadmill running in recreationally active and trained individuals (10). Mercer et al. (22) demonstrated no significant differences in $\text{VO}_{2\text{peak}}$ and peak heart rate between the elliptical ergometer and treadmill in physically active, college aged students. These findings suggest that the use of the elliptical ergometer in clinical and health-fitness settings may be an option, and it may be a viable alternative to traditional exercise modalities for determining fitness levels in certain populations.

Typically, health-fitness settings do not have access to open circuit spirometry. Therefore, standardized metabolic equations such as those developed by the American College of Sports Medicine (ACSM) are routinely used to estimate $\text{VO}_{2\text{peak}}$ based on the speed and grade, or power output (PO) for the final workload achieved during peak treadmill or cycle ergometer exercise, respectively. Exercise prescriptions are then based on percentages of these estimations of $\text{VO}_{2\text{peak}}$ and maximal heart rate (HR_{max}) (1). Research has demonstrated that the ACSM metabolic equations may overestimate $\text{VO}_{2\text{peak}}$ (3, 16); however, it is a common practice to use estimations of $\text{VO}_{2\text{peak}}$ based upon the final workload achieved during progressively incremented exercise tests. Cross-modal exercise prescriptions are then implemented without fully knowing modality-prescription congruence. Additionally, predictions of $\text{VO}_{2\text{peak}}$ based upon submaximal heart rate (HR) and VO_2 estimated by ACSM metabolic equations are commonly used without knowing the accuracy of the models. Manufacturers of the elliptical ergometer have recently developed equations to estimate VO_2 during elliptical ergometer exercise; however, these equations remain proprietary. Therefore, unlike the ACSM metabolic equations for the treadmill and cycle ergometer, the validity of these equations has not been established.

There are situations in the health-fitness arena that merit the use of submaximal exercise testing to predict $\text{VO}_{2\text{peak}}$. However, such predictions require the attainment of steady state

at each stage of the exercise test (1). Steady state may not always be attained at each exercise stage potentially leading to inaccurate predictions of $\text{VO}_{2\text{peak}}$. A common test used in health-fitness settings to predict $\text{VO}_{2\text{peak}}$ is the YMCA cycle ergometer protocol. The protocol uses individual linear regression predictions based upon 2 to 4 submaximal steady state HR/ VO_2 responses (15). The literature is inconclusive as to the accuracy of these predictions methods (2, 13, 25, 30). Garatachea et al. (13) concluded that the YMCA cycle protocol was accurate in determining submaximal energy expenditure, however the protocol resulted in an overestimation of $\text{VO}_{2\text{peak}}$. Although findings related to the accuracy of prediction models based upon submaximal responses have been inconsistent, clinicians still frequently utilize submaximal steady state cycle ergometer protocols to predict $\text{VO}_{2\text{peak}}$. While it is generally accepted that predictions of $\text{VO}_{2\text{peak}}$ require submaximal steady state HR responses, there is evidence that there are significant relationships between steady state and non-steady state cardiovascular variables during incremental exercise testing (14, 20). Bot and Hollander (5) found that $\text{VO}_{2\text{peak}}$ could be estimated from individual HR/ VO_2 regression lines during non-steady state exercise. This finding has practical implications, as steady state is not always achieved during exercise tests conducted in health-fitness settings.

Therefore, the primary purpose of this investigation was to evaluate practical aerobic testing methods to estimate and predict $\text{VO}_{2\text{peak}}$. HR_{max} responses and congruence of final workload VO_2 estimates using the ACSM metabolic equations and MET levels on the elliptical ergometer digital displays as the criterion measures were examined. Another aim was to evaluate predictions of $\text{VO}_{2\text{peak}}$ from submaximal steady state and steady state/non-steady state HR responses. We hypothesized that HR_{max} and $\text{VO}_{2\text{peak}}$ estimations from final workloads will not differ between the treadmill and elliptical ergometer. Additionally, we hypothesized that predictions of $\text{VO}_{2\text{peak}}$ from submaximal steady state and steady state/non-steady state HR responses will not differ from estimations based on the final workload within each modality.

METHODS

Experimental Approach to the Problem

This investigation used a cross-sectional, estimation design consisting of an orientation session and 3 experimental trials. The independent variables for this project were 1) mode of exercise and 2) estimation/prediction methods for $\text{VO}_{2\text{peak}}$. The dependent variables were estimated and predicted $\text{VO}_{2\text{peak}}$ as well as HR_{max} . Estimates of physiological variables ($\text{VO}_{2\text{peak}}$ and HR_{max}) were completed during graded exercise tests using the three modes of exercise (e.g. treadmill, cycle ergometer and elliptical ergometer). Intra and intermodal comparisons of the peak physiological responses were conducted. This study employed exercise testing modalities and protocols commonly used in health-fitness settings. Our aim was to gain a better understanding of physiological responses using different exercise modalities and methods commonly used to predict and estimate $\text{VO}_{2\text{peak}}$. Standard spreadsheet packages for determining $\text{VO}_{2\text{peak}}$ from submaximal exercise test responses, an easy to use computer feature for development of prediction models, were used in this investigation. Strict control of laboratory testing procedures was implemented to strengthen

internal validity. Ecological validity was a primary concern in order to enhance the application of the present findings.

Subjects

Seventeen recreationally active, college-aged women from the University of Tennessee at Chattanooga volunteered to participate in this study. Subjects were (mean $\pm$ SE) 21.9 $\pm$.3 yrs old, 165.4 $\pm$ 1.5 cm tall, 22.0 $\pm$ 1.5 % fat and weighed 64.0 $\pm$ 2.5 kg. Fifteen subjects were non-smokers. All testing took place during the Spring semester (e.g. February–April) at the University of Tennessee at Chattanooga Physical Activity Center. The Institutional Review Board approved all of the procedures associated with the investigation. Each subject provided written informed consent prior to participation. Subjects were instructed to avoid food, tobacco, and caffeine for at least 3 hours prior to each testing session (1), as well as to refrain from alcohol for at least 24 hours before reporting for testing. Subjects were also instructed to be adequately hydrated and to not engage in exercise or strenuous physical activity for 24 hours prior to testing (1).

Procedures

The testing of each subject was completed in 4 separate sessions, with a minimum of 48 hours between each session. Each session lasted no longer than 1 hour.

Session 1—The initial session consisted of each subject completing a detailed health history questionnaire and a physical activity readiness questionnaire (PAR-Q). Next, height, weight, body composition and leg strength were assessed. Subjects were then familiarized with each exercise modality. Subjects were allowed to exercise briefly (i.e. 5–10 min) on any modality they were not comfortable using. Height and weight were assessed with a Detecto D-439 medical scale (Cardinal Scale Mfg. Co., Webb City, MO). Body composition was assessed using a 7-site skin fold equation (18) with Lange skinfold calipers (Cambridge Scientific Ind., Cambridge, MA). The average of two measurements within 2 mm at each site were summed and used in the body density equation to determine % body fat. Leg strength was assessed with a 1 repetition maximum (1-RM) test using the Hammer Strength iso-lateral leg press (LP) (Hammer Strength, Falmouth, KY). Subjects completed the 1-RM according to the ACSM guidelines (1).

Sessions 2–4—Sessions 2–4 consisted of progressively incremented treadmill, cycle ergometer and elliptical ergometer tests administered in a randomly assigned, counterbalanced order. HR was measured every 5 s of exercise using a downloadable Polar HR monitor (Polar Electro, Kempele, Finland). Tests were terminated owing to subject fatigue or inability to maintain the target cadence. Verbal encouragement was given *ad libitum* during each test. A 5 min cool down consisting of subjects exercising at the warm-up intensity followed each exercise testing session.

Treadmill session—Treadmill tests were completed on the Precor C934 (Precor, Inc., Woodinville, WA) using a modified Astrand protocol. This consisted of a 3 min walk at 80.4 m $\cdot$ min⁻¹, followed by 2 min at 134 m $\cdot$ min⁻¹. Thereafter, speed was increased and

maintained at $160.8 \text{ m} \cdot \text{min}^{-1}$ for the remainder of the test, and grade was increased by 2.5% every 2 min. The test continued until subjects reached a volitional end point.

Cycle ergometer session—A Monark 818E cycle ergometer (Monark Exercise AB, Vansboro, Sweden) was used for all cycle ergometry tests. The first stage was 3 min in duration and PO was 25 watts. PO during the second stage was increased by 75 watts for 2 min. Thereafter PO was increased by 25 watts every 2 min. Throughout the test, a cadence of 50 revolutions per min was maintained using a metronome. Subjects also used the digital display mounted on the cycle to aid in maintaining the proper cycling cadence. The test continued until subjects reached a volitional end point or were unable to maintain the pedal cadence within 5 revolutions per min for 10 consecutive seconds.

Elliptical ergometer session—The Precor EFX 546 Elliptical Cross-Trainer (Precor, Inc., Woodinville, WA) was used for the elliptical exercise tests. A variation of the protocol used by Dalleck et al., (10) was used. A constant incline of level 6 was maintained during each stage. Subjects performed a 3 min warm-up at a resistance of level 1 and a cadence of $100 \text{ strides} \cdot \text{min}^{-1}$. At min 4, resistance was increased to level 5 and cadence was increased to $125 \text{ strides} \cdot \text{min}^{-1}$. At min 6, and then each 2 min stage thereafter, resistance was increased by 2 levels. Cadence was increased and maintained at $150 \text{ strides} \cdot \text{min}^{-1}$. Subjects maintained cadence by using a metronome and the digital display on the elliptical ergometer. The test continued until subjects could no longer continue due to fatigue or were unable to maintain cadence within $20 \text{ strides} \cdot \text{min}^{-1}$ of the target for 10 consecutive seconds. Holding onto the hand rails for support was not permitted, unless stability was lost and subjects needed to regain their balance.

VO_{2peak} assessment and submaximal prediction methods

ACSM metabolic equations were used as the criterion measure to estimate VO₂ at each exercise stage for the treadmill and cycle ergometer. VO₂ values for each exercise stage were calculated using the MET value from the digital display as the criterion measure during elliptical ergometer exercise. For all subjects, HR and VO₂ values up to 85% of the individual's age-predicted HR_{max} were used to predict VO_{2peak}. The following 2 linear regression techniques were used to predict VO_{2peak}: 1.) two submaximal steady state HRs (i.e. steady state HR was achieved if HR between min 1 and 2 of a workload did not differ by more than $\pm 6 \text{ beats} \cdot \text{min}^{-1}$) and 2.) a submaximal steady state/non-steady state HR method. If steady state was achieved, the last 3 HR's of the final minute of the stage were averaged and used in the prediction models. Only two steady state values were used for the prediction of VO_{2peak}. In the second prediction method, if steady state was not achieved, the highest HR in that stage was used. HR's up to 85% of age-predicted HR_{max} were used in the prediction. Additionally, the HR corresponding to 85% of age-predicted HR_{max} was used in the prediction of VO_{2peak} if it was measured between the 1st and 2nd min of the stage. Essentially, the second prediction method is a combination of steady state and non-steady state HR responses. Thus, the number of submaximal data points used in the individual linear regression varied between subjects. The forecasting function of Excel 2003 (Microsoft Corp., Redmond, WA) was used to determine individual linear regression lines for VO_{2peak} from submaximal HR/VO₂ responses.

Statistical Analyses

A 2-way within-subjects analysis of variance (ANOVA) was performed on $\text{VO}_{2\text{peak}}$ values as a function of mode (treadmill, cycle ergometer, and elliptical ergometer) and prediction methods (ACSM equations/MET level digital displays, steady state predictions, and steady state/non-steady state predictions). A one-way within-subjects ANOVA was performed on predicted and measured HR_{max} values for each mode of exercise. In order to find the pattern of differences on $\text{VO}_{2\text{peak}}$ depending on mode by prediction model as well as for HR_{max} , *post hoc* pairwise comparisons were performed using the Bonferroni adjustment. Correlations between relative LP strength (1-RM to body weight ratio) and $\text{VO}_{2\text{peak}}$ estimated from final workloads for each mode of exercise were also conducted. Significance was set *a priori* at $\alpha = .05$.

RESULTS

A number of subjects did not satisfy criteria for the steady state and steady state/non-steady state prediction models. One subject reached 85% of age-predicted HR_{max} before two submaximal HR's were obtained during the cycle ergometer exercise test. During the elliptical ergometer exercise test, 4 subjects reached 85% of age-predicted HR_{max} before two submaximal HR's were obtained. The missing values were computed using the Expectation Maximization (EM) algorithm proposed by Dempster et al. (11). Little's MCAR test indicated the data were missing completely at random, $\chi^2(178) = 124.24$, $p = .99$, (19). The missing rates are displayed in Table 1.

There was a significant main effect in $\text{VO}_{2\text{peak}}$ values among exercise modes averaged across estimation and prediction methods (i.e. ACSM metabolic equations, steady state and steady state/non-steady state models), $F(2, 32) = 159.36$, $p < .001$, partial $\eta^2 = .91$. The cycle ergometer $\text{VO}_{2\text{peak}}$ was significantly less ($36.33 \pm .9 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) than both treadmill ($47.8 \pm 1.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and elliptical ergometer $\text{VO}_{2\text{peak}}$ values ($48.7 \pm 1.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), $p < .001$. A significant main effect was also observed for estimation and prediction methods, $F(2, 32) = 6.26$, $p < .01$, partial $\eta^2 = .28$. $\text{VO}_{2\text{peak}}$ estimated by the ACSM metabolic equations or MET level digital displays ($42.4 \pm .9 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) were significantly lower than the steady state prediction model ($45.6 \pm .7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$; $p < .05$) and the steady state/non-steady state prediction model ($44.9 \pm 1.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$; $p < .05$). There were no significant differences between steady state and steady state/non-steady state prediction models, $p = 1.00$.

There was a significant exercise mode X prediction method interaction for $\text{VO}_{2\text{peak}}$, Huynh-Feldt $F(2.44, 39.01) = 6.92$, $p < .001$, partial $\eta^2 = .30$. In order to examine the pattern of differences in $\text{VO}_{2\text{peak}}$ as a function of exercise modalities and prediction methods, simple main effects were performed. The exercise mode X prediction method simple main effect indicated there were significant differences within each $\text{VO}_{2\text{peak}}$ prediction method, (a) ACSM equations/MET level digital displays, $F(2, 32) = 63.61$, $p < .001$, partial $\eta^2 = .80$; (b) steady state prediction model, $F(2, 32) = 114.18$, $p < .001$, partial $\eta^2 = .88$; (c) steady state/non-steady state prediction model, $F(2, 25.02) = 45.72$, $p < .001$, partial $\eta^2 = .74$. The pattern of differences in $\text{VO}_{2\text{peak}}$ values between prediction methods for the 3 modes of exercise were also examined using simple main effects. There were significant differences

among prediction methods for the treadmill and elliptical ergometer, (a) treadmill, $F(2, 32) = 4.80$, $p < .05$, partial $\eta^2 = .23$; (b) elliptical ergometer, Huynh-Feldt $F(1.46, 23.30) = 9.16$, $p < .01$, partial $\eta^2 = .36$. There were no significant differences among predictions for the cycle ergometer, $ps > .89$. Results of simple main effects comparisons are presented in Figure 1.

There was a significant difference in $HR_{\max}$ values between the age-predicted and mode of exercise, $F(3, 48) = 12.23$, $p < .001$, $\eta^2 = .43$. The cycle ergometer measured $HR_{\max}$ was significantly lower than age-predicted and treadmill $HR_{\max}$ (185.1 ± 2.6 vs. $198.1 \pm .4$ and 196.7 ± 2.6 beats $\cdot \text{min}^{-1}$, $ps = 0.001$). There were no other significant differences, $ps = .07$. Pairwise comparisons of $HR_{\max}$ are reported in Figure 2.

Correlation analyses demonstrated that relative LP strength was significantly related to elliptical ergometer $VO_{2\text{peak}}$ estimated from the final workload using the MET level digital displays ($r = .56$, $p < .05$). However, no significant relation was found between relative LP strength and treadmill $VO_{2\text{peak}}$ ($r = .30$, $p > .05$) and cycle ergometer $VO_{2\text{peak}}$ ($r = .34$, $p > .05$) estimates from the final workload achieved using the ACSM metabolic equations.

DISCUSSION

The purpose of this study was to examine the accuracy of methods that are commonly used in commercial fitness settings to predict $VO_{2\text{peak}}$. In this study, a large percentage of subjects were unable to satisfy the criteria for attainment of steady state HR responses (41.2–58.8%) during progressively incremented exercise tests for all 3 modalities. This could potentially pose a problem in health-fitness settings, as the HR responses to a variety of submaximal exercise protocols are used for the prediction of aerobic functional capacity. The present results demonstrated $VO_{2\text{peak}}$ predictions from steady state/non-steady state HR responses did not differ from VO_2 calculated from metabolic equations corresponding to the final workload achieved during the treadmill and cycle ergometer exercise tests. This finding is in agreement with Bot and Hollander (5). They concluded that determination of VO_2 by measuring the HR is not limited to steady state exercise and that VO_2 could be estimated from individual HR/ VO_2 regression lines during non-steady state activities (5). Additionally, ACSM equations (treadmill) and MET level digital displays (elliptical ergometer) resulted in similar estimations of $VO_{2\text{peak}}$ corresponding to the final workload achieved during the exercise tests. As expected, the cycle ergometer $HR_{\max}$ and $VO_{2\text{peak}}$ for all estimation and prediction methods were significantly lower than both the treadmill and elliptical ergometer. These findings have practical applications in clinical and health-fitness settings.

The literature has shown that individual regression equations using HR/ VO_2 responses during progressively incremented exercise exhibit a linear relationship during non-steady state leg and arm exercise (5). Therefore, the authors concluded that VO_2 could be estimated from individual HR/ VO_2 regression lines during various non-steady state activities (5). The results of the current study support this finding and the use of steady state/non-steady state predictions of $VO_{2\text{peak}}$ when open circuit spirometry equipment is not available. Steady state/non-steady state $VO_{2\text{peak}}$ predictions were closer to ACSM equation estimates of $VO_{2\text{peak}}$ during final workload estimates than steady state predictions during treadmill and

cycle ergometer exercise tests. Additionally, the number of missing data was highest for steady state prediction models for all 3 modes of exercise. Minimal data were missing when responses were used in the steady state/non-steady state prediction models. This finding indicates an advantage of the steady state/non-steady state prediction models over the steady state prediction models. It may not be necessary to continue to exercise in a stage until steady state is reached. Submaximal HR responses used in individual linear regression models resulted in accurate predictions of $\text{VO}_{2\text{peak}}$ regardless of whether steady state was met. This suggests that predictions of $\text{VO}_{2\text{peak}}$ from submaximal HR responses do not require steady state HR values.

In the present investigation, the $\text{VO}_{2\text{peak}}$ estimated from the final elliptical ergometer workload did not differ from $\text{VO}_{2\text{peak}}$ estimates using ACSM metabolic equations during treadmill exercise testing. Additionally, the elliptical ergometer HR_{max} ($191.4 \pm 3.1 \text{ beats} \cdot \text{min}^{-1}$) did not differ from treadmill HR_{max} ($196.7 \pm 2.6 \text{ beats} \cdot \text{min}^{-1}$). This is in agreement with several studies that have previously reported similar physiological responses during submaximal and maximal treadmill and elliptical ergometer exercise (7, 9, 10, 12). Mercer and colleagues (22) demonstrated that the elliptical ergometer provided a range of exercise intensities similar to that of the treadmill. They found that HR_{max} , $\text{VO}_{2\text{peak}}$ and maximal ratings of perceived exertion did not differ between the elliptical ergometer and treadmill. However, in the current study, steady state and steady state/non-steady state predictions of $\text{VO}_{2\text{peak}}$ during elliptical ergometry were greater than the VO_2 determined from the manufacturer's proprietary equations. It appears that the elliptical ergometer METs may not be accurate through the full range of submaximal and maximal exercise intensities. Several studies provide evidence of overestimations of caloric expenditure by the elliptical ergometer displays (23, 27, 28). In the later exercise stages, the present subjects had difficulty moving the pedals thus it appears that leg strength was a mitigating factor for performance at higher intensities. The significant correlation ($r = .56$) of leg strength and elliptical ergometer $\text{VO}_{2\text{peak}}$ estimated from final workloads provides support for this.

Metabolic equations may overestimate maximal oxygen consumption when steady state is not achieved (1). It is critical to acknowledge that these are just estimations of $\text{VO}_{2\text{peak}}$ and that values from the ACSM metabolic equations would need to be compared to those measured using open circuit spirometry. Familiarity with the exercise modality may be important when choosing an exercise mode for assessment of aerobic functional capacity. A familiarity session for each mode of exercise was provided to each subject. However, specific amounts of previous experience and patterns of exercise usage for each modality were not documented in the current study.

Metabolic equations for treadmill and cycle ergometer exercise have been published and validated. Equations for determining MET levels for the elliptical ergometer have been determined by the manufacturer and their validity is unknown. Only recently have $\text{VO}_{2\text{peak}}$ prediction equations and metabolic equations for steady state VO_2 been developed for the elliptical ergometer (8, 9); however at the time this study was conducted these equations were not available. Thus, for the purposes of this study VO_2 values were based on MET level digital displays. Fitness facilities typically do not have aerobic metabolic analyzers at their disposal, thus estimations of submaximal VO_2 are commonly used to predict $\text{VO}_{2\text{peak}}$.

However, the results of this study indicate a mismatch between $\text{VO}_{2\text{peak}}$ estimated from final workloads achieved and $\text{VO}_{2\text{peak}}$ predicted from submaximal HR/ VO_2 responses during elliptical ergometry. More research is needed to determine the congruence between measured VO_2 via open circuit spirometry, metabolic equations and proprietary MET equations developed by manufacturers.

PRACTICAL APPLICATIONS

Submaximal HR responses are commonly used in clinical and health-fitness settings to predict $\text{VO}_{2\text{peak}}$ due to a lack of sophisticated open circuit spirometry equipment. The most accurate predictions of maximal oxygen uptake and $\text{VO}_{2\text{peak}}$ are achieved when steady state is reached at each submaximal workload (1). However, the present findings indicate that the steady state/non-steady state prediction method results in predicted values that are comparable to those obtained from steady state models. As such, steady state/non-steady state models may be used in place of steady state HR predictions methods. Maximal oxygen uptake assessments are often completed using the treadmill, with the actual exercise prescriptions being implemented on many other modalities. It would appear that cross-modal prescriptions could be generated for treadmill and elliptical ergometer exercise because of the similarity in HR_{max} and estimated $\text{VO}_{2\text{peak}}$. However, care must be taken when prescribing exercise based on predicted $\text{VO}_{2\text{peak}}$ from elliptical ergometer exercise tests, as exercise intensities may increase exponentially and not linearly at higher workloads.

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Figure 1.

VO_{2peak} for each exercise mode and prediction method. Data are means $\pm$ SE. n = 17.

*Significantly different ($p < .05$) than ACSM metabolic equations for the treadmill.

**Significantly lower compared to both treadmill and elliptical ergometer for each prediction method, $p < .001$. †Significantly lower compared to steady state prediction models ($p < .001$) and steady state/non-steady state prediction models for the elliptical ergometer ($p < .01$).

Figure 2. Mode specific and age-predicted HR_{max}. Data are means $\pm$ SE. n = 17. *Significantly lower compared to age-prediction and treadmill HR_{max}, $p < .001$

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Table 1

Missing data analysis from subject pool of n = 17.

Modality	Prediction Models	Missing	%
Treadmill	ACSM Equations	0	0.0
	Steady State	10	58.8
	Steady State/Non-Steady State	0	0.0
Cycle Ergometer	ACSM Equations	0	0.0
	Steady State	8	47.7
	Steady State/Non-Steady State	1	5.9
Elliptical Ergometer	MET level digital displays	0	0.0
	Steady State	7	41.2
	Steady State/Non-Steady State	4	23.5