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Validation of a New Method for Estimating $\dot{V}O_{2max}$ Based on $\dot{V}O_2$ Reserve

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ABSTRACT

SWAIN, D. P., J. A. PARROTT, A. R. BENNETT, J. D. BRANCH, and E. A. DOWLING. Validation of a New Method for Estimating $\dot{V}O_{2max}$ Based on $\dot{V}O_2$ Reserve. *Med. Sci. Sports Exerc.*, Vol. 36, No. 8, pp. 1421–1426, 2004. **Purpose:** The American College of Sports Medicine's (ACSM) preferred method for estimating maximal oxygen consumption ($\dot{V}O_{2max}$) has been shown to overestimate $\dot{V}O_{2max}$, possibly due to the short length of the cycle ergometry stages. This study validates a new method that uses a final 6-min stage and that estimates $\dot{V}O_{2max}$ from the relationship between heart rate reserve (HRR) and $\dot{V}O_2$ reserve. **Methods:** A cycle ergometry protocol was designed to elicit 65–75% HRR in the fifth and sixth minutes of the final stage. Maximal workload was estimated by dividing the workload of the final stage by %HRR. $\dot{V}O_{2max}$ was then estimated using the ACSM metabolic equation for cycling. After the 6-min stage was completed, an incremental test to maximal effort was used to measure actual $\dot{V}O_{2max}$. Forty-nine subjects completed a pilot study using one protocol to reach the 6-min stage, and 50 additional subjects completed a modified protocol. **Results:** The pilot study obtained a valid estimate of $\dot{V}O_{2max}$ (r = 0.91, SEE = 3.4 $mL\cdot min^{-1}\cdot kg^{-1}$) with no over- or underestimation (mean estimated $\dot{V}O_{2max}$ = 35.3 $mL\cdot min^{-1}\cdot kg^{-1}$, mean measured $\dot{V}O_{2max}$ = 36.1 $mL\cdot min^{-1}\cdot kg^{-1}$), but the average %HRR achieved in the 6-min stage was 78%, with several subjects attaining heart rates considered too high for submaximal fitness testing. The second study also obtained a valid estimate of $\dot{V}O_{2max}$ (r = 0.89, SEE = 4.0 $mL\cdot min^{-1}\cdot kg^{-1}$) with no over- or underestimation (mean estimated $\dot{V}O_{2max}$ = 36.7 $mL\cdot min^{-1}\cdot kg^{-1}$, mean measured $\dot{V}O_{2max}$ = 36.9 $mL\cdot min^{-1}\cdot kg^{-1}$), and the average %HRR achieved in the 6-min stage was 64%. **Conclusions:** A new method for estimating $\dot{V}O_{2max}$ from submaximal cycling based on $\dot{V}O_2$ reserve has been found to be valid and more accurate than previous methods. **Key Words:** MAXIMAL OXYGEN CONSUMPTION, CYCLE ERGOMETRY, EXERCISE TESTING, FITNESS

There are several methods in use for estimating the maximal oxygen consumption ($\dot{V}O_{2max}$) of healthy clients in a fitness setting, such as the popular Åstrand nomogram that utilizes a single 6-min cycle ergometry stage (5). The American College of Sports Medicine (ACSM) recommends a multi-stage cycle ergometry test, similar to that developed by the YMCA (10), in which the heart rate (HR) at the end of each stage is plotted against the respective workload, then the estimated maximum workload is extrapolated from this plot, and $\dot{V}O_{2max}$ is estimated by applying the metabolic equation for cycling to the maximum workload (3).

In its 1991 guidelines, the ACSM's protocol used 2-min stages that terminated at 70% of age-predicted maximum HR (1). Greiwe et al. (11) evaluated this protocol and found that, although it had a reasonably good correlation (r = 0.79, SEE = 6.2 $mL\cdot min^{-1}\cdot kg^{-1}$), it overestimated $\dot{V}O_{2max}$ by 26% on average. Reasons for this overestimation may have been the short length of the stages (not allowing HR to reach steady-state) and the low termination HR. The ACSM revised the protocol in its 1995 guidelines, increasing the stage length to 3 min (provided the heart rates at the end of second and third minutes were within 6 bpm), and increasing the termination point to 70% of heart rate reserve (HRR) or 85% of HR_{max} (2). Swain and Wright (17) evaluated this protocol and found that, despite a reasonably good correlation (r = 0.79, SEE = 8.2 $mL\cdot min^{-1}\cdot kg^{-1}$), it overestimated $\dot{V}O_{2max}$ by 28% on average.

The purpose of the current study was to design a new method for estimating $\dot{V}O_{2max}$ that would improve accuracy and precision. We propose that longer stage lengths would produce a higher HR at any given workload. A study of cyclists who exercised at a constant, submaximal intensity found that HR increased by 5 bpm from the first 5-min period to the second, despite a preliminary warm-up (14). Increasing the stage length of the $\dot{V}O_{2max}$ estimation pro-

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tocol from 3 to 6 min should increase HR and thereby reduce the overestimation of maximal workload and maximal $\dot{V}O_2$. The Åstrand nomogram utilized a single 6-min stage but reportedly has only modest accuracy (13). Multiple 6-min stages would likely improve accuracy, but the total duration of the protocol would be excessive. Recent studies have demonstrated that a one-to-one relationship exists between heart rate reserve and $\dot{V}O_2$ reserve ($\dot{V}O_2R$; the difference between resting and maximum $\dot{V}O_2$) (18,19). During cycle ergometry in particular, the correlation between %HRR and %$\dot{V}O_2R$ is indistinguishable from the line of identity, e.g., when a subject is at 70% of HRR, then he or she is at 70% of $\dot{V}O_2R$ (18). Thus, we hypothesized that HR and workload data from a single 6-min stage could provide an accurate estimation of $\dot{V}O_{2max}$ based on the HRR:$\dot{V}O_2R$ relationship. A key challenge was to design an ergometry protocol that allowed a consistent level of %HRR to be reached at the end of the 6-min stage.

METHODS

Subjects. Two studies were performed, a pilot study testing one ergometry protocol and a second study testing a modified protocol. Fifty-nine subjects participated in the first study and 57 in the second. A total of 13 subjects were excluded for failure to reach criteria for $\dot{V}O_{2max}$, and four others were excluded for other reasons (two for equipment malfunctions, one for an error in performing the protocol, one for an excessive HR response). Thus, 49 and 50 subjects, from the respective protocols, successfully completed all testing, and their characteristics are presented in Table 1. There were 24 males and 25 females in the pilot study, and 25 each of males and females in the second study. All subjects were 18–44 yr old and were identified as low risk for heart disease based on ACSM criteria (3). Only low risk subjects were used because maximal exercise testing was performed to validate the submaximal protocol. All subjects provided written informed consent in accordance with Institutional Review Board guidelines.

Procedures. Subjects were asked to abstain from alcohol, caffeine, and other drugs 24 h before testing, and to avoid eating for 1 h before testing. Six subjects in the pilot study were smokers and were asked to abstain for 24 h. No subjects in the second protocol were smokers. No subjects were taking blood pressure medication. Once the subjects were screened and informed consent obtained, each subject's height and mass were recorded. A three-lead ECG (for the pilot study) or a chest strap heart rate monitor (Polar; for the second study) was used to monitor HR. Resting HR was recorded after 5–6 min of quiet, seated rest. Subjects then mounted a calibrated cycle ergometer (Monark 818e for the pilot study, 828e for the second study), and the seat was adjusted to provide a slight bend (approximately 5°) in the knee at full extension. Pedal straps were used. The ambient temperature was approximately 21°C during testing, and a fan was directed at the subjects during exercise to enhance cooling. Each subject performed a submaximal cycle ergometer test at a cadence of 60 rpm. After the submaximal test, the subjects were given a brief cool-down (2–3 min) while being fitted with a mouthpiece and two-way valves (Hans-Rudolph) to collect expired air for the determination of oxygen consumption ($\dot{V}O_2$) and respiratory exchange ratio (RER) using a metabolic cart (SensorMedics 2900c). The O_2 and CO_2 analyzers of the metabolic cart were calibrated against known gas concentrations, and its flowmeter was calibrated using a 3.0-L syringe. The maximal incremental test began with 2 min at the power level of the last stage of the submaximal test, followed by 1-min increments of ~15 W, i.e., 0.25 kg at 60 rpm, until volitional exhaustion. Resistance setting adjustments of 0.25 kg were made by visual interpolation on the Monark ergometer scale. Maximal oxygen consumption was defined as the highest $\dot{V}O_2$ obtained over any continuous 60-s time period, provided the RER was $\geq$ 1.10 (17–19).

Pilot protocol. The submaximal test in the pilot protocol consisted of two stages. The first stage was three min at a resistance setting of 1 kg (approx. 60 W). The HR was recorded during the last 15 s of the third minute and used to calculate a resistance for the second stage, intended to elicit 70% of HRR; that is, resistance $= 0.70(HR_{max} - HR_{rest})/(HR_{3\text{-}min} - HR_{rest})$, where HR_{max} was estimated as 220 − age in years. The subject immediately began the second stage, and pedaled at the designated resistance for 6 min, unless adjusted as follows. HR was measured at the end of the third minute of the second stage and if less than the target HR by 10 bpm or more, then the resistance was increased by 0.5 kg and the new workload was performed for 6 min. HR was recorded during the last 2 min of the final stage and averaged for later data analysis.

Second protocol. The pilot protocol resulted in heart rates deemed too high for fitness testing of the general population (see Results), so a new protocol was designed to gradually approach a target HR of 65–75% HRR in 1-min stages. Through trial-and-error, slightly different protocols were developed for active and inactive subjects of different body masses. In brief, it was found that the workload for active subjects could be increased by 15 $W \cdot min^{-1}$ until the subject reached 55% HRR, and then the subject could complete an additional 5 min at that level without exceeding 75% HRR. However, inactive subjects taken up to 55% HRR generally overshot 75% HRR in the following 5 min, so a check stage of 3 min was developed at 45% HRR. The specific protocols are provided in Table 2. Active subjects were defined as individuals engaging in $\geq$ 90 min of vigorous aerobic activity per week (indicated by having a more difficult time talking while exercising; including running, vigorous cycling, competitive soccer) or engaging in $\geq$ 120

TABLE 1. Subject characteristics.

	Age (yr) Mean ± SD Range	Height (cm) Mean ± SD Range	Mass (kg) Mean ± SD Range	$\dot{V}O_2$max ($mL \cdot min^{-1} \cdot kg^{-1}$) Mean ± SD Range
Pilot study	26 ± 7	168 ± 14	71.8 ± 16.8	36.1 ± 9.8
(*N* = 49)	19–44	155–196	44–112	16.4–61.6
Second study	29 ± 6	169 ± 9	71.2 ± 13.2	36.9 ± 8.8
(*N* = 50)	18–44	154–191	47–92	19.9–58.0

TABLE 2. Cycle ergometry protocol for estimating $\dot{V}O_{2max}$.

For all subjects: 1. Measure HR after 5–6 min of quiet seated rest 2. Calculate 45%, 55%, and 75% HRR (using 220 − age to estimate HR_{max}) 3. Select a protocol below based on subject's activity status* and body mass 4. Instruct subject to pedal at 60 rpm 5. Measure HR during last 15 sec of each min of the test 6. Terminate test if 75% HRR is exceeded	
Inactive subjects < 90 kg 1. Set initial resistance (R) at 0.25 kg 2. Increase R 0.25 kg·min^{-1} until 45% HRR is reached 3. Remain at this stage for 2 additional min 3a. If HR in 3rd min is 55% HRR or more, continue for 3 additional min to complete 6-min stage 3b. If HR in 3rd min is < 55% HRR, increase R by 0.25 kg·min^{-1} until 55% HRR is reached, then continue at that level for 5 additional min to complete 6-min stage 4. Record and average HR from 5th and 6th min of final stage for analysis	Active subjects < 90 kg 1. Set initial resistance (R) at 0.25 kg 2. Increase R by 0.25 kg·min^{-1} until 55% HRR is reached 3. Remain at this stage an additional 5 min to complete 6-min stage 4. Record and average HR from 5th and 6th min of final stage for analysis
Inactive subjects ≥ 90 kg 1. Set initial resistance (R) at 0.5 kg 2. Increase R 0.5 kg·min^{-1} until 45% HRR is reached 3. Remain at this stage for 2 additional min 3a. If HR in 3rd min is 55% HRR or more, continue for 3 additional min to complete 6-min stage 3b. If HR in 3rd min is < 55% HRR, increase R by 0.25 kg·min^{-1} until 55% HRR is reached, then continue at that level for 5 additional min to complete 6-min stage 4. Record and average HR from 5th and 6th min of final stage for analysis	Active subjects ≥ 90 kg 1. Set initial resistance (R) at 0.5 kg 2. Increase R by 0.5 kg·min^{-1} until 55% HRR is reached 3. Remain at this stage an additional 5 min to complete 6-min stage 4. Record and average HR from 5th and 6th min of final stage for analysis

* Active defined as engaging in ≥ 90 min of vigorous, or ≥ 120 min of moderate, aerobic activity per week.

min of moderate aerobic activity per week (indicated by being able to talk while exercising; including brisk walking, moderate cycling).

Data analysis. For both submaximal protocols, heart rates were recorded during the last 15 s of the fifth and sixth minutes of the final stage, averaged, and converted to a percentage of HRR. Even though true maximal HR was available, maximal HR was estimated as 220 − age in the HRR calculation, to ensure that the methodology matched how the test would be used in a fitness setting. Estimated maximal power was then calculated by dividing the power used in the 6-min stage by %HRR. Then, estimated $\dot{V}O_{2max}$ was calculated from the ACSM metabolic equation for cycling; that is, $\dot{V}O_2 = 7 + 10.8$(power)/body mass (3). The procedure for estimating $\dot{V}O_{2max}$ is summarized in Table 3. For comparative purposes, the $\dot{V}O_{2max}$ was also estimated by applying the Åstrand nomogram (5) to the power and HR of the 6-min stage and adjusting with the Åstrand age-correction factor (4). In the second protocol, HR was monitored every min, and the min-to-min rise during the 6-min stage was analyzed in a posthoc evaluation.

Statistics. Subject characteristics and results of exercise tests are presented as mean ± SD. To determine the validity of the $\dot{V}O_{2max}$ estimations, a linear regression was performed on the estimated and actual values. This was done once for the new method of estimation based on $\dot{V}O_2R$ and once for the Åstrand nomogram estimation. The SEE and the correlation coefficient were determined for each regression, and the regressions were tested for significance by a Student *t*-test for the correlation coefficient. The accuracy of the estimation was further evaluated by comparing the mean values of the estimated and measured $\dot{V}O_{2max}$ using a Student *t*-test. *Post hoc* comparisons of HR responses within the 6-min stage were made by Student *t*-test. For all statistical tests, significance was judged at an alpha level of 0.05.

TABLE 3. Procedure for estimating $\dot{V}O_{2max}$ by the $\dot{V}O_2$ reserve method.

1. Calculate workload of 6-min stage:
   power in watts* = (R in kg)(9.81 m·s^{-2}) (6 m·s^{-1})
2. Determine %HRR attained in the 5th and 6th min of the 6-min stage:
   First, average the 5th and 6th min HR values.
   Second, estimate HR_{max} as 220 − age in years.
   $\%HRR = (HR_{6\text{-min}} - HR_{rest})/(HR_{max} - HR_{rest})$
3. Estimate maximal workload as:
   maximal power = (power of 6-min stage)/(%HRR)
4. Estimate $\dot{V}O_{2max}$ from ACSM metabolic equation for cycling (3):
   $\dot{V}O_{2max} = 7 + 10.8$(maximal power)/(body mass)

* Power calculation assumes that cadence is 60 rpm, in which case the flywheel travels 6 m·s^{-1}; R is the resistance setting; this calculation may be approximated as: power = (R in kg)(60 rpm); 9.81 m·s^{-2} is the acceleration of gravity and converts kilograms of resistance to newtons of force.

RESULTS

Results from pilot protocol. Results for males and females were similar and have been combined. The estimated $\dot{V}O_{2max}$ derived from the pilot protocol using the $\dot{V}O_2R$ method was strongly correlated to the measured $\dot{V}O_{2max}$ (r = 0.91, $P < 0.001$, SEE = 3.4 mL·min^{-1}·kg^{-1}) and did not over- or underestimate the measured $\dot{V}O_{2max}$ (mean ± SD estimated $\dot{V}O_{2max}$ = 35.3 ± 8.4 mL·min^{-1}·kg^{-1}, mean measured $\dot{V}O_{2max}$ = 36.1 ± 9.8 mL·min^{-1}·kg^{-1}). Using the Åstrand nomogram on the same data yielded a somewhat lower correlation (r = 0.83, $P < 0.001$, SEE = 5.4 mL·min^{-1}·kg^{-1}), without over- or underestimation (mean estimated $\dot{V}O_{2max}$ = 36.7 ± 9.8 mL·min^{-1}·kg^{-1}).

The average HR achieved in the fifth and sixth minutes of the final submaximal stage was 78 ± 8.4% HRR. Individuals who obtained higher heart rates exhibited stronger correlations of estimated and measured $\dot{V}O_{2max}$. Using the $\dot{V}O_2R$ method of estimating $\dot{V}O_{2max}$, the correlation for the 12 subjects who completed the submaximal test below 70% HRR yielded r = 0.85 ($P < 0.001$) and SEE = 4.8 mL·min^{-1}·kg^{-1}, the correlation for the 17 subjects between 70 and 80% HRR yielded r = 0.89 ($P < 0.001$) and SEE = 4.2 mL·min^{-1}·kg^{-1}, whereas the correlation for the 20 subjects finishing above 80% HRR yielded r = 0.97 ($P < 0.001$) and SEE of 2.1 mL·min^{-1}·kg^{-1}.

Results from second protocol. Results for males and females were similar and have been combined. As seen in the Figure, the estimated $\dot{V}O_{2max}$ derived from the modified protocol using the $\dot{V}O_2R$ method was highly correlated to the measured $\dot{V}O_{2max}$ (r = 0.89, $P < 0.001$, SEE = 4.0 mL·min^{-1}·kg^{-1}) and did not over- or underestimate the measured $\dot{V}O_{2max}$ (mean estimated $\dot{V}O_{2max}$ = 36.7 ± 8.4 mL·min^{-1}·kg^{-1}, mean measured $\dot{V}O_{2max}$ = 36.9 ± 8.8 mL·min^{-1}·kg^{-1}). The strength of the correlation was similar for the 30 active subjects (r = 0.87, $P < 0.001$, SEE = 3.8 mL·min^{-1}·kg^{-1}) and 20 inactive subjects (r = 0.82, $P < 0.001$, SEE = 4.1 mL·min^{-1}·kg^{-1}), with no over- or underestimation of $\dot{V}O_{2max}$ in either group. Using the Åstrand nomogram on the same data yielded a somewhat lower correlation (r = 0.82, $P < 0.001$, SEE = 5.1 mL·min^{-1}·kg^{-1}) and a significant ($P = 0.002$) overestimation of $\dot{V}O_{2max}$ by 8% on average (mean estimated $\dot{V}O_{2max}$ = 39.8 ± 11.1 mL·min^{-1}·kg^{-1}). This overestimation was more pronounced with the active subjects than inactive subjects.

The average HR attained during the fifth and sixth minutes of the final submaximal stage was 64 ± 4.8% HRR. Only 3 of the 50 subjects exceeded 75% HRR, achieving 78%, 79%, and 83% HRR. They were retested on a separate day using a 6-min stage that was 15 W lower in power than their initial test, and all achieved heart rates below 65% HRR. There was a statistically significant ($P < 0.001$) increase in HR from the third to sixth minute of 5.7 ± 3.7 bpm. The amount of increase was related to the degree of leveling-off observed from the second to third minutes, in that those subjects who increased < 4 bpm from the second to third minutes (N = 33) increased by only 4.5 ± 3.3 bpm from the third to sixth minutes, whereas those who increased by 4–6 bpm from the second to third minutes (N = 14) increased by 7.5 ± 3.2 bpm from the third to sixth minutes (significantly greater increase, $P = 0.007$). Three subjects experienced an increase of 7–8 bpm from the second to third minutes, and their HR increased a further 7–15 bpm from the third to the sixth minutes. For all subjects as a group, HR did not reach a true plateau, increasing from the fifth to sixth minutes by 1.9 ± 2.5 bpm ($P < 0.001$).

DISCUSSION

This study has found that a new method of estimating $\dot{V}O_{2max}$, based on the relationship between heart rate reserve and $\dot{V}O_2$ reserve and utilizing a gradual approach to a 6-min cycle ergometer stage, is valid and highly accurate. Previous studies of the method used by the American College of Sports Medicine obtained lower r values and greater SEE values, and also found that the ACSM method significantly overestimates the measured $\dot{V}O_{2max}$ by more than 25% on average (11,17).

The most likely reason that the ACSM method overestimates $\dot{V}O_{2max}$ is that the stage length is too short. The current ACSM protocol calls for 3-min stages, with the stipulation that the heart rate values at the end of the second and third minutes must be within 6 bpm of each other (otherwise, additional minutes would be added to the stage until ± 6 bpm was achieved) (3). However, an increase of 6 bpm from one minute to the next suggests that HR would rise further if the stage were continued. In the current study, subjects who experienced a 4–6 bpm increase in HR from the second to third minutes had a further 7.5 bpm increase by the sixth minute. Higher HR values, when plotted against their respective workloads, would predict lower maximal workloads and lower $\dot{V}O_{2max}$ values. In the current study,

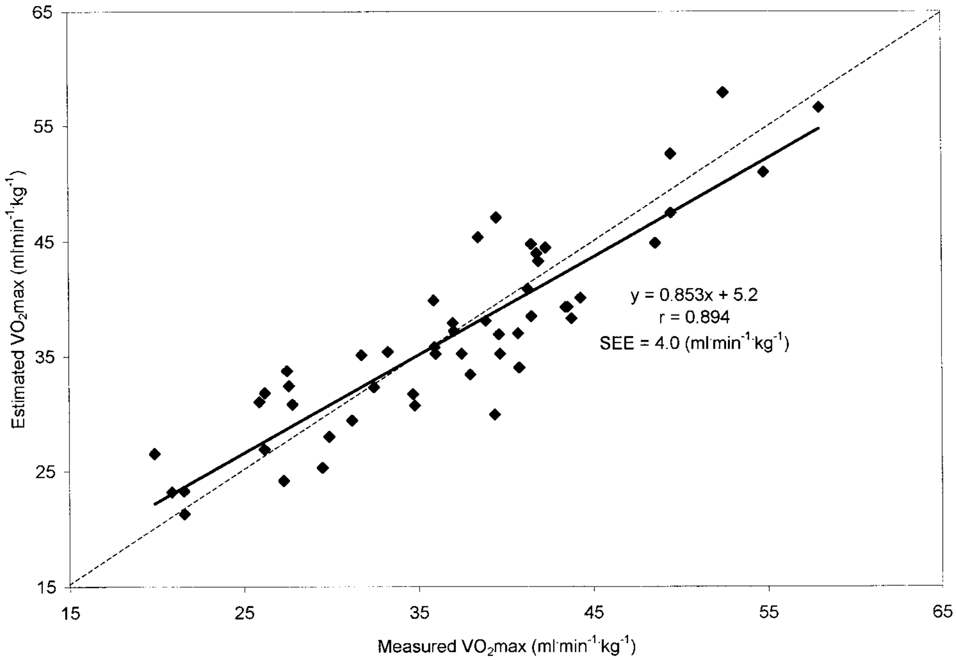

FIGURE 1—Regression of estimated $\dot{V}O_{2max}$ versus measured $\dot{V}O_{2max}$, where $\dot{V}O_{2max}$ was estimated using the $\dot{V}O_2$ reserve method and the protocol described in Table 2.

HR did not reach a true plateau within 6 min but had risen sufficiently to produce an accurate estimate of $\dot{V}O_{2max}$.

A variety of other cycling protocols have been used to estimate $\dot{V}O_{2max}$ (5,9,10,12,15,16). The most accurate protocol is Mastropaolo's (15), which included physiological data such as RER in a multiple regression. However, fitness testing facilities are generally not equipped to perform such an analysis. Other than the ACSM method, the best-known protocol is the Åstrand 6-min single-stage test with nomogram (5). The original report on this method did not perform a correlation, but indicated that the standard deviation for the difference between actual and estimated values of $\dot{V}O_{2max}$ ranged from 6.7% to 14.4%, depending on gender and workload (5). A review of other studies found the Åstrand test to have only modest accuracy, with r values averaging 0.62 (13). Applying the Åstrand nomogram to data obtained in the current study yielded a good correlation ($r = 0.82$, $SEE = 5.1$ $mL \cdot min^{-1} \cdot kg^{-1}$), although it was somewhat less than that obtained with the $\dot{V}O_2$ reserve method ($r = 0.89$, $SEE = 4.0$ $mL \cdot min^{-1} \cdot kg^{-1}$) and was found to slightly overestimate the actual $\dot{V}O_{2max}$. The stronger correlation with the Åstrand nomogram in this study compared with others may be due to the protocol that was used to bring the subjects to a relatively high and consistent target heart rate. The higher correlation of the $\dot{V}O_2$ reserve method than the Åstrand nomogram using the same data is likely due to the strength of the one-to-one relationship for heart rate reserve and $\dot{V}O_2$ reserve that was used to estimate $\dot{V}O_{2max}$ (18,19).

The pilot protocol used in this study elicited heart rates in the 6-min stage that were more varied and higher on average than elicited in the second protocol. Of interest from the pilot protocol was the finding that the strongest correlation in the estimation of $\dot{V}O_{2max}$ was observed in subjects who attained the highest submaximal heart rates ($r = 0.97$, $SEE = 2.1$ $mL \cdot min^{-1} \cdot kg^{-1}$). This is to be expected on the basis that the closer the submaximal test is to maximal effort, the less error would occur in extrapolating to maximum. However, for the safety of clients being tested in a fitness facility, it is prudent to set an upper target heart rate limit at a moderate level to minimize the potential for serious cardiovascular complications. The second protocol in this study was designed to gradually approach a target heart rate of no more than 75% HRR. This value was chosen because the ACSM's current recommendation is to allow 70% HRR to be reached in the final 3-min stage (3). We targeted this level of exertion, allowing up to 75% HRR given the longer stage length. The protocol was very successful in accomplishing this, with only 3 of 50 subjects exceeding the target heart rate by a small amount, and still yielded good validity. Thus, this protocol, as described in Table 2, is recommended for use in fitness testing. In our experience, it is no more difficult to perform than the YMCA branching protocol (10), and the estimation of $\dot{V}O_{2max}$ from the data (Table 3) is simpler than the graphical extrapolation used in the ACSM and YMCA methods.

Using the protocol in Table 2, three individuals exceed the 75% HRR limit in the fifth minute. They were successfully retested on a separate day using 15 W less power. Fitness professionals encountering such subjects should retest them to obtain accurate estimates of $\dot{V}O_{2max}$ but might consider adding 3%HRR units to the value obtained in the fifth minute and proceeding with the estimation described in Table 3. This amount was the difference between the %HRR during the fifth minute and the average %HRR for the fifth and sixth minutes for the three subjects in this study and resulted in similar $\dot{V}O_{2max}$ estimations as their retests. If a test is terminated earlier than the fifth minute (which never occurred in this study), then the client should be rescheduled for another test at a lower power.

Only adults at a low risk of heart disease up to an age of 44 yr were subjects in the current study. Thus, the findings apply to this population. It is likely that good validity would be obtained in the estimation of $\dot{V}O_{2max}$ with this method in older/higher risk populations, because the one-to-one relationship of HRR to $\dot{V}O_2$ reserve has been established in older populations of patients with coronary heart disease and diabetes mellitus (6,7). Nonetheless, further research to validate this method is recommended in other populations, particularly middle-aged adults at moderate risk of heart disease who might commonly be tested in fitness facilities. As with any cycle ergometry test, it should also be noted that higher aerobic capacities may be obtained by some subjects during treadmill exercise (8). The HRR:$\dot{V}O_2$ reserve relationship has been established in treadmill exercise (19), and further research should explore submaximal testing with that mode.

CONCLUSION

This study has evaluated a new method for the estimation of $\dot{V}O_{2max}$ based on the relationship of heart rate reserve to $\dot{V}O_2$ reserve and using a cycle ergometry protocol that gradually approaches a 6-min stage at no more than 75% HRR. The new method was found to have a stronger correlation than that previously demonstrated for the method in current use by the ACSM and, unlike the ACSM method, did not overestimate $\dot{V}O_{2max}$.

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