Impact of the Exercise Mode on Exercise Capacity*

Bicycle Testing Revisited

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Study objective: To test the performance of a tool designed to estimate functional capacity in order to select a bicycle ramp protocol yielding a test duration from 8 to 12 min in healthy individuals, and to assess differences in exercise responses between bicycle and treadmill tests.
Participants and measures: Forty-one healthy and physically active volunteers (10 women; median age, 37 years; interquartile range [IQR], 29.5 to 41 years) performed an individualized ramp exercise protocol on a bicycle ergometer and a treadmill in random order. Prior to testing, the Veterans Specific Activity Questionnaire (VSAQ) combined with a modified variant of the VSAQ nomogram (metabolic equivalents [METs] derived from VSAQ and age with the modified nomogram, resulting in METs nomogram) was used to estimate exercise capacity and to select the treadmill protocol. The corresponding bicycle work capacity nomogram (in watts) was derived by the following equation: (METs nomogram − 1) × body weight/3.486.
Results: Using treadmill tests, all 41 participants (100%) achieved maximal exercise from 8 to 12 min, as compared to 33 participants (80%) for the bicycle tests (p = 0.003). Peak oxygen uptake ($\dot{V}o_2$) [bicycle: median, 49.7 mL/kg/min (IQR, 45.4 to 56.6 mL/kg/min); vs treadmill: median, 53.1 mL/kg/min (IQR, 47.3 to 57.7 mL/kg/min; p < 0.0001)] was lower using the bicycle compared to the treadmill. However, the difference in peak $\dot{V}o_2$ values between the two exercise modes was lower (2.6 mL/kg/min; IQR, 1.1 to 4.3 mL/kg/min), corresponding to 4.6% (IQR, 2.4 to 8.5%) of the lower of both values than reported in previous studies, and seven participants (17%) even achieved a higher peak $\dot{V}o_2$ using the bicycle.
Conclusions: A modified version of the VSAQ can be effectively used to select appropriate ramp rates for exercise testing using a bicycle ergometer in healthy individuals. Differences in maximal responses are less than those previously reported, suggesting that the bicycle ergometer is an appropriate alternative to the treadmill test in healthy volunteers.

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Key words: bicycle ergometry test; nomogram; oxygen uptake; treadmill test

Abbreviations: estimated METs = peak metabolic equivalents estimated from mechanical resistance of the bicycle and speed and grade of the treadmill, respectively; IQR = interquartile range; measured METs = peak exercise metabolic equivalents determined directly from peak oxygen uptake (by division by 3.5); MET = metabolic equivalent; METs nomogram = metabolic equivalents derived from the Veterans Specific Activity Questionnaire and age with the modified nomogram; METs VSAQ = metabolic equivalents obtained from the Veterans Specific Activity Questionnaire; PAS = physical activity score; RER = respiratory exchange ratio; $\dot{V}co_2$ = carbon dioxide output; $\dot{V}o_2$ = oxygen uptake; VSAQ = Veterans Specific Activity Questionnaire

E xercise capacity is a powerful predictor of mortality and has been shown to be a superior prognostic marker than established risk factors such as history of smoking, hypertension, or myocardial infarction.[1,2] An individual's exercise capacity depends not only on age, gender, and fitness level, but also on the mode of exercise employed and the exercise protocol applied.[3] There are two modes of dynamic exercise that are most often used for exer-

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cise testing: the treadmill and the bicycle ergometer. Treadmill testing is more popular in North America, whereas in Europe bicycle testing is more commonly used. Studies comparing the two modes of exercise have generally revealed a higher peak oxygen uptake ($\dot{V}O_2$),[4–8] higher peak heart rate,[5,6,8] and higher sensitivity in detecting coronary ischemia using the treadmill compared to the bicycle.[8] Despite these advantages of treadmill testing, many physicians prefer bicycle tests because ECG and BP recordings are easier to assess due to lesser upper body motion.[3] In addition, some elderly or obese patients prefer the bicycle, where less coordination is required and the risk of falling is lower.

Previous data from treadmill studies[6,9] suggest a test duration from 8 to 12 min optimizes the exercise test, and this recommendation is reflected in the American Heart Association and other exercise testing guidelines.[10] Although data are sparse, the same rule appears to apply for bicycle testing.[4] However, selection of the most appropriate bicycle protocol to yield a targeted test duration may be more challenging than that for treadmill testing. A questionnaire-based nomogram to facilitate selection of an individual's most suitable treadmill ramp protocol (Veterans Specific Activity Questionnaire [VSAQ]) has been developed[11] and prospectively validated.[12] However, a similar tool for bicycle exercise testing does not exist. It is unknown whether the VSAQ can be applied for bicycle testing because it was derived from treadmill tests. Additionally, it has been shown to overpredict metabolic equivalent (MET) levels at the lowest range of exercise capacity (< 4), and to underpredict MET levels at the highest range of exercise capacity (> 9).[13]

We have demonstrated that a modified variant of the VSAQ nomogram accurately predicts exercise capacity (as assessed by ventilatory gas exchange) and allows selection of a protocol resulting in a treadmill time from 8 to 12 min in 100% of healthy volunteers with moderate-to-high exercise capacity undergoing treadmill ramp testing.[14] The aims of the present analysis were as follows: (1) to test the performance of the modified VSAQ nomogram with respect to selection of a bicycle exercise protocol targeting a test duration from 8 to 12 min; and (2) to compare cardiopulmonary responses to treadmill and bicycle ramp testing in healthy subjects. In particular, we aimed to address whether previous data from studies in North America showing markedly higher (up to 20%) values for peak $\dot{V}O_2$[4–8,15] and higher peak heart rates[5,6,8] using the treadmill vs the bicycle could be confirmed in a group of healthy Europeans, among whom cycling is a more common recreational activity.

Materials and Methods

Study Population

Healthy male and female volunteers from 18 to 80 years of age were eligible for the study. Subjects with a history of cardiovascular or pulmonary disease, use of cardiovascular drugs, or any acute condition (*eg*, common cold) were excluded from the study. Written informed consent, including anonymous use of the data, was obtained from each participant. History of smoking and regular physical activity were recorded. We determined a physical activity score (PAS), where 1 U was equal to 20 min of regular exercise per week, to assess the average amount of physical activity per week.

Nomogram

To estimate each individual's exercise tolerance prior to exercise testing, the VSAQ was used (Table 1). This questionnaire

Table 1—*METs VSAQ**

VSAQ	Activities
1	Eating, getting dressed, working at desk
2	Taking a shower, shopping, cooking, walking down eight steps
3	Walking slowly on a flat surface for one or two blocks, a moderate amount of work around the house, such as vacuuming, sweeping the floors, or carrying groceries
4	Light yard work (*ie*, raking leaves, weeding, sweeping, or pushing a power mower), painting, or light carpentry
5	Walking briskly, social dancing, washing the car
6	Play nine holes of golf carrying your own clubs, heavy carpentry, mow lawn with push mover
7	Carrying 60 lb, perform heavy outdoor work (*ie*, digging, spading soil, etc)
8	Carrying groceries upstairs, move heavy furniture, jog slowly on flat surface, climb stairs quickly
9	Bicycling at a moderate pace, sawing wood, jumping rope (slowly)
10	Brisk swimming, bicycle up a hill, jog six miles per hour
11	Carry a heavy load (*ie*, a child or firewood) up two flights of stairs
12	Running briskly, continuously (level ground, 8 min per mile)
13	Any competitive activity, including those that involve intermittent sprinting, running competitively, rowing competitively, bicycle riding

*From Myers et al.[11]

provides a list of activities with increasing intensity in terms of METs.[11,12] One MET is defined as the energy expended while sitting quietly, which is equivalent to a total body $\dot{V}O_2$ of approximately 3.5 mL/kg of body weight per minute for an average adult.[1] In an interview, participants were instructed to determine from the questionnaire the first activity that would typically cause fatigue or shortness of breath leading to discontinuation after 5 to 10 min (METs obtained from the VSAQ [METs VSAQ]). To obtain the predicted maximal exercise capacity (METs derived from the VSAQ and age with the modified nomogram [METs nomogram], a modified variant of the nomogram was employed as previously described.[14] In brief, the original VSAQ nomogram was redrawn based on our observations of working capacity in young and middle-aged sedentary as well as trained individuals, as shown in Figure 1. The METs nomogram value was obtained by drawing a line from the METs VSAQ through the corresponding value for age on the right side of the nomogram.[11,14] For women, the obtained value was multiplied by 0.85 since peak $\dot{V}O_2$ values in women have been reported to be 15 to 30% below those of men.[3]

Exercise Tests

All participants performed a treadmill ramp test (CS-200; Schiller; Baar, Switzerland) and a bicycle ramp test (Ergo 500S; Schiller) on 2 different days in random sequence. The work capacity for the bicycle test (bicycle work capacity nomogram, expressed in watts) was estimated as follows (equation 1)[3]: (METs nomogram − 1) × body weight (kilograms)/3.486.

Accordingly, the most suitable protocol from a predefined set of eight bicycle ramp protocols ranging from 140 to 400 W (to achieve maximum exercise capacity within the range of 8 to 12 min) was selected depending on the bicycle work capacity nomogram. Similarly, the ramp rate for the treadmill test was chosen from a predefined set of five ramp protocols for exercise capacities ranging from 9 to 17 METs (to achieve maximum exercise capacity within the range of 8 to 12 min); the most suitable was selected depending on the METs nomogram obtained.

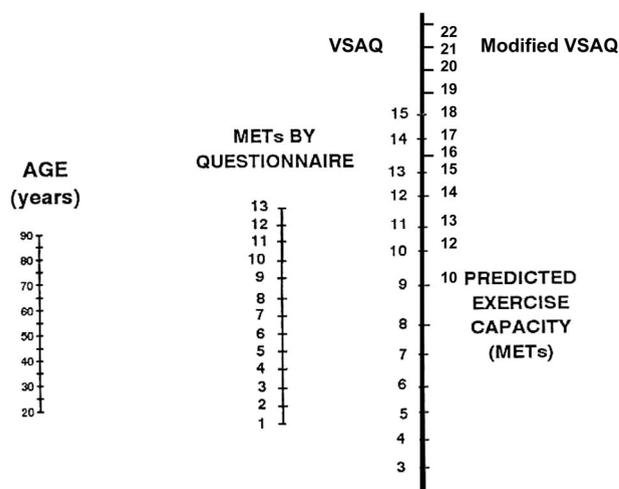During the tests, a three-lead ECG was recorded continuously.

FIGURE 1. Nomogram to predict exercise capacity from age and answers to the VSAQ. The original VSAQ nomogram (reprinted from Myers et al,[11] with permission from Excerpta Medica, Inc.) as well as the modified variant are given. For women, the obtained MET nomogram value must be multiplied by 0.85.

BP (by indirect arm cuff sphygmomanometry; Schiller-Reomed; Dietikon, Switzerland) was assessed every 2 min. Expired gases were acquired continuously, and $\dot{V}O_2$ and carbon dioxide output ($\dot{V}CO_2$) were recorded in rolling 30-s averages (ErgoScope; Ganshorn; Niederlauer, Germany). Calibration of the system was performed before each test with a 3-L syringe. Participants were not allowed to perform vigorous physical activity on the day of the test. During the tests, subjects were verbally encouraged to exercise until exhaustion. No test was terminated due to an untoward response (exertional hypotension, systolic BP > 250 mm Hg, or the occurrence of clinically relevant arrhythmias). Standard equations were used to estimate exercise capacity (peak METs estimated from mechanical resistance of the bicycle and speed and grade of the treadmill, respectively [estimated METs]).[16]

Assessment of Exertion

The level of perceived effort was assessed using the Borg 6–20 scale every 2 min and at peak exercise.[17] In addition, the respiratory exchange ratio (RER), defined as $\dot{V}CO_2$ divided by $\dot{V}O_2$, was determined at rest (sitting on the bicycle or standing on the treadmill) and at peak exercise (maximum RER).

Statistical Analysis

Statistical analysis was performed using a commercially available software package (SPSS version 10.1; SPSS; Chicago, IL). A nonnormal distribution of the data was assumed. Continuous data were expressed as the median value and interquartile range (IQR). The Fisher Exact Test was used to compare categorical data. For comparison of continuous data, the Mann-Whitney U or the Wilcoxon rank-sum tests were used as appropriate. A two-sided p value < 0.05 was considered statistically significant. Standard Spearman correlations were determined between METs VSAQ, METs nomogram, estimated METs, and peak exercise METs determined directly from peak $\dot{V}O_2$ (by division by 3.5) [measured METs] for the bicycle exercise test.

A multiple regression procedure was performed to identify predictors of peak $\dot{V}O_2$ achieved on the bicycle. The model was developed using a stepwise technique and by consideration of clinically relevant pretest variables. These included patient age, gender, body mass index, history of smoking, PAS, METs nomogram, resting heart rate, and resting RER. In addition, a second multiple regression procedure was performed to identify variables derived from the bicycle exercise test without using gas exchange techniques (age, body height, body weight, resting heart rate, peak heart rate, and body weight-corrected bicycle work capacity), in order to predict measured METs as derived from peak $\dot{V}O_2$.

RESULTS

Study Population

The study population consisted of 45 volunteers, 2 of whom were excluded due to incorrect application of the nomogram. In two other participants, a significant air leak during metabolic testing precluded inclusion in the study analysis. Thus, the present results are based on the data of 41 healthy volunteers (31 men and 10 women), whose baseline characteristics are given in Table 2.

Table 2—Baseline Characteristics of Participants (n = 41)*

Age, yr	37 (29.5–41)
Female sex	10 (24)
Height, cm	178 (171–183)
Weight, kg	75 (63.5–81)
Body mass index, kg/m^2	23.9 (20.1–25.7)
Smoking	5 (12)
PAS (20-min units per week)	6 (2.5–9)
METs VSAQ	12 (10–12)
METs nomogram	15 (14–16.5)

*Data are expressed as median (IQR) or No. (%).

Nomogram and Test Duration

The exercise tests were terminated for generalized fatigue in all participants. By nomogram-based selection of the most suitable ramp protocol, the exercise time was similar for the bicycle test (median, 9.6 min; interquartile range [IQR], 8.2 to 10.6 min) and the treadmill test (median, 9.5 min; IQR, 8.8 to 10.1 min) [p = 0.46], and thus near the "ideal" value of 10 min. During treadmill testing, all participants exercised within the recommended range from 8 to 12 min, whereas during bicycle testing 33 subjects (80%) fell within this range (p = 0.003). Of those failing to do so, the cycling time was too short in five men (by 7, 18, 20, 22, and 78 s, respectively) and too long in one man (by 73 s) and two women (by 16 s and 30 s). There was no significant difference in test duration between women and men (women: 10.3 min [IQR, 8.6 to 12 min]; vs men: 9.0 min [IQR, 8.2 to 10.5 min]; p = 0.14).

Bicycle vs Treadmill Exercise Responses

Exercise test results of the individualized bicycle and treadmill ramp protocol are compared in Table 3. Resting heart rate was slightly but significantly different prior to the two tests (bicycle: 75 beats/min [IQR, 70 to 83 beats/min]; vs treadmill: 78 beats/min [IQR, 72 to 91 beats/min]; p = 0.02), whereas peak heart rate did not differ (bicycle: 183 beats/min [IQR, 179 to 190 beats/min]; vs treadmill: 183 beats/min [IQR, 179 to 191 beats/min]; p = 0.41). The maximum RER was similar (bicycle: 1.22 [IQR, 1.17 to 1.26]; vs treadmill: 1.21 [IQR, 1.18 to 1.27]; p = 0.38), whereas the maximal perceived level of exertion was slightly higher using the bicycle as compared to the treadmill test (bicycle: 20 [IQR, 19 to 20]; vs treadmill: 19 [IQR, 19 to 20]; p = 0.003). Peak $\dot{V}O_2$ was lower using the bicycle compared to the treadmill (bicycle: 49.7 mL/kg/min [IQR, 45.4 to 56.6 mL/kg/min]; vs treadmill: 53.1 mL/kg/min [IQR, 47.3 to 57.7 mL/kg/min]; p < 0.0001. This difference remained significant when the ratio of peak $\dot{V}O_2$/maximum RER and peak $\dot{V}O_2$/peak rating of perceived exertion (Borg) were compared to correct for possible differences in effort between the two tests. Thirty-four subjects (83%) achieved a higher peak $\dot{V}O_2$ with the treadmill, as compared to 7 participants (17%) doing so with the bicycle test (p < 0.0001). The median absolute difference between peak $\dot{V}O_2$ during the treadmill and peak $\dot{V}O_2$ using the bicycle protocol was 2.6 mL/kg/min (IQR, 1.1 to 4.3 mL/kg/min), corresponding to 4.6% (IQR, 2.4 to 8.5%) of the lower of both values. The maximal difference between peak $\dot{V}O_2$ achieved with the two modes of exercise was 6.1 mL/min/kg (corresponding to 13.2% of the lower of both values). Younger age (p = 0.016), shorter bicycle test duration (p = 0.016), and longer treadmill test duration (p = 0.047) were independent predictors for a higher percentage difference between peak $\dot{V}O_2$ during the treadmill and peak $\dot{V}O_2$ using the bicycle protocol.

Neither body weight-corrected bicycle work ca-

Table 3—Comparison Between Bicycle and Treadmill Ramp Protocol (n = 41)*

Variables	Bicycle Ramp	Treadmill Ramp	p Value
Test order (first test)	20 (49)	21 (51)	0.83
Exercise time, s	574 (492–633)	572 (528–605)	0.46
Achievement of an exercise time between 8 min and 12 min	33 (80)	41 (100)	0.003
Resting heart rate, beats/min	75 (70–83)	78 (72–91)	0.02
Peak heart rate, beats/min	183 (179–190)	183 (179–191)	0.41
Peak rating of perceived exertion (Borg)	20 (19–20)	19 (19–20)	0.003
Peak RER	1.22 (1.17–1.26)	1.21 (1.18–1.27)	0.38
Peak $\dot{V}O_2$, mL/kg/min	49.7 (45.4–56.6)	53.1 (47.3–57.7)	< 0.0001
Peak $\dot{V}O_2$/effort (maximum Borg), mL/kg/min	2.61 (2.32–2.91)	2.76 (2.48–3.03)	< 0.0001
Peak $\dot{V}O_2$/maximum RER, mL/kg/min	42.2 (36.5–46.6)	44.5 (38.1–47.6)	< 0.0001
Peak estimated METs	17.1 (15.1–19.2)	16.7 (15.8–17.7)	0.08
Peak measured METs	14.2 (13.0–16.2)	15.2 (13.5–16.5)	< 0.0001
Peak $\dot{V}CO_2$, mL/min/kg	60.8 (55.8–68.4)	63.6 (58.8–68)	0.004

*Data are presented as median (IQR) or No. (%).

pacity (men: 4.6 W/kg [IQR, 4.0 to 5.5 W/kg]; vs women: 4.6 W/kg [IQR, 4.0 to 4.9 W/kg]; p = 0.53) nor peak $\dot{V}o_2$ during the bicycle test (men: 49.7 mL/kg/min [IQR, 45.6 to 57 mL/kg/min]; vs women: 49.7 mL/kg/min [IQR, 44.6 to 55.8 mL/kg/min]; p = 0.92) differed between men and women, whereas during the treadmill test estimated METs were slightly higher in men as compared to women (men: 17.1 [IQR, 15.9 to 18.2]); vs women: 16.4 [IQR, 14.9 to 16.6]; p = 0.047). Peak $\dot{V}o_2$ did not differ between genders (men: 53.1 mL/kg/min [IQR, 47.2 to 59.3 mL/kg/min]); vs women: 53.7 mL/kg/min [IQR, 47.2 to 57.3 mL/min/kg]; p = 0.83) for the treadmill tests. However, there was a trend for a younger age in women as compared to men (women: 33 years [IQR, 28.5 to 40.3 years]; vs men: 37 years [IQR, 31.0 to 42.0 years]; p = 0.08).

Predicted vs Measured Exercise Capacity During the Bicycle Test

During the bicycle ramp protocol, measured METs were significantly lower (by 6%) than METs nomogram (p = 0.006; Fig 2). Spearman correlation coefficients between measures of exercise capacity are shown in Table 4. In a multiple regression procedure, METs nomogram, PAS, and age were significant pretest predictors of measured METs. The final regression equation for measured exercise capacity for the bicycle ramp protocol based on pretest variables was as follows (equation 2):

Table 4—Spearman Correlation Coefficients Between Measures of Exercise Capacity for the Bicycle Ramp Protocol

Variables	METs VSAQ	METs Nomogram	Estimated METs	Measured METs
METs VSAQ				
METs nomogram	0.77			
Estimated METs	0.52	0.59		
Measured METs	0.46	0.50	0.90	

$$measured\ METs = 9.125$$
$$+\ 0.465\ (METs\ nomogram) + 0.157\ (PAS)$$
$$-\ 0.080\ (age\ in\ years)$$

Estimated vs Measured Exercise Capacity During the Bicycle Test

During the bicycle ramp protocol, measured METs were significantly lower (by 20%) than estimated METs (p < 0.0001; Fig 2). However, measured METs and estimated METs were strongly related (r = 0.90, p < 0.0001). Multiple regression revealed that in addition to the body weight-corrected bicycle work capacity (p < 0.0001), height (p = 0.03), and resting heart rate (p = 0.04; ie, heart rate while quietly sitting on the bicycle before the test) were significant predictors of measured METs
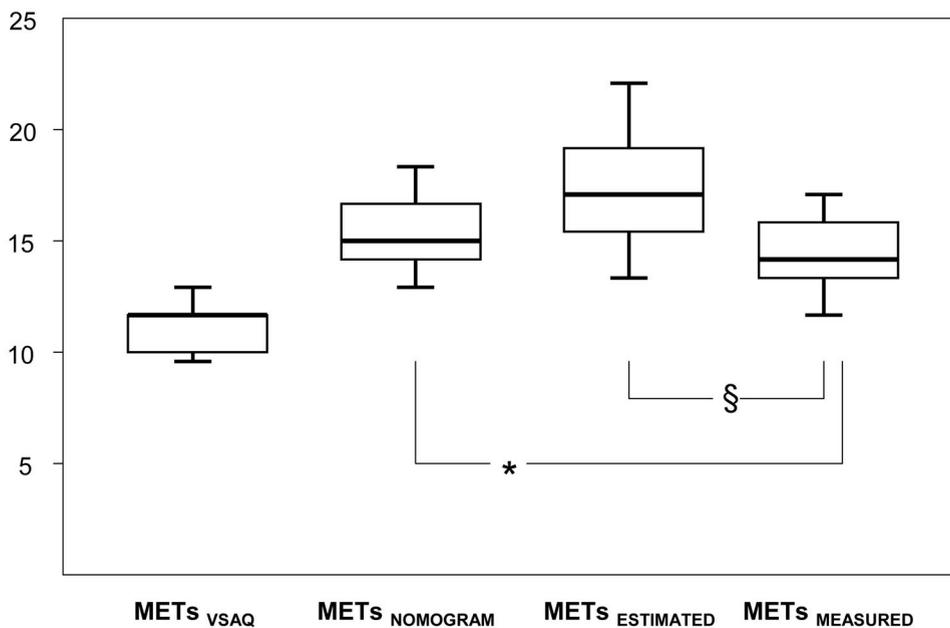

FIGURE 2. Box plots showing the different measures of exercise capacity. Median values and IQRs are shown as black line and boxes respectively. The 5% and 95% percentiles are also indicated. *p = 0.006; §p < 0.0001.

as derived from peak $\dot{V}o_2$ (R^2 for the total model of 0.87). The following equation was found for measured exercise capacity including only exercise test parameters obtained without gas exchange techniques (equation 3):

$$measured \ METs = 6.685$$
$$+ \ 2.457 \ (body \ weight\text{-}corrected \ bicycle$$
$$work \ capacity \ in \ watts \ per \ kilogram)$$
$$+ \ 0.026 \ (resting \ heart \ rate$$
$$in \ beats \ per \ minute)$$
$$- \ 0.032 \ (height \ in \ centimeters)$$

DISCUSSION

The present study demonstrates that our modified variant of the VSAQ nomogram can be applied for treadmill ramp testing in healthy individuals with moderate to high exercise capacity,[14] and also yields an exercise duration from 8 to 12 min in 80% of subjects in the same population undergoing bicycle ramp testing. In addition, we have shown that in this population the difference in peak $\dot{V}o_2$ between the bicycle and treadmill was < 5%, and that almost 20% of participants even achieve a higher $\dot{V}o_2$ with the bicycle than with the treadmill.

Nomogram and Test Duration

Current guidelines emphasize that exercise protocols should be individualized based on the subject being tested, and suggest an approximate 10-min targeted ramp or ramp-type protocol.[10] However, selection of a protocol yielding the recommended exercise duration requires knowledge of the level of disability or fitness of the subject. In this context, the VSAQ is a convenient tool since it provides a list of daily activities with corresponding MET values facilitating selection of a suitable treadmill protocol. A particular MET level is approximately the same for a light or a heavy subject, and therefore allows direct comparison between individuals. In contrast, watts achieved on the bicycle are body weight-dependent units, and normalization for body weight is required for comparison between individuals. Although this is an easy calculation, the association between a given degree of fitness and a watt level is more difficult to estimate. This may explain why many physicians fail to appropriately estimate bicycle work capacity as observed in daily practice.

Direct transfer of the VSAQ concept to bicycle testing is feasible, as shown by the high percentage of participants achieving a test duration from 8 to 12 min in the present study. All male participants who exercised < 8 min using the bicycle test achieved peak exercise within a range of 8 to 12 min using the treadmill. This might be explained by the somewhat lower peak $\dot{V}o_2$ for the bicycle, as compared to the treadmill ramp test. Assuming that the difference in peak $\dot{V}o_2$ between the treadmill and bicycle in our study group would not be as high as previously reported,[4–8] we applied the same nomogram for both the treadmill and the bicycle without introduction of a correction factor. In contrast to the men, there were two women with exercise durations that would be considered too long. Surprisingly, estimated METs and peak $\dot{V}o_2$ during the bicycle test did not differ between men and women in our population, which may be due to the younger age in the women as compared to the men, or more likely a bias in the selection of the female study population. We had recruited both active and sedentary subjects of both genders to participate in the study. However, women who volunteered for the study were clearly well trained in the vast majority, and thus the correction factor of 0.85 (based on earlier findings[3]) might have been unsuitable for our female population. A correction factor in the range of 0.90 to 0.95, rather than at 0.85, may have been more appropriate for the current study group.

Bicycle vs Treadmill Exercise Responses

As expected, peak $\dot{V}o_2$ was higher on the treadmill as compared to the bicycle protocol. Previous studies[4–8] suggest that this difference typically ranges from 6 to 20%. In one of the widely cited studies,[4] peak $\dot{V}o_2$ values in healthy and diseased subjects (41 men; age, 61 ± 7 years [$\pm$ SD]) with different modes (bicycle and treadmill) of exercise and different protocols (two staged protocols; one ramp protocol for each mode of exercise) were evaluated. A significantly higher peak $\dot{V}o_2$ was observed on the treadmill as compared to the bicycle (treadmill, 21.4 ± 8 mL/kg/min; vs bicycle, 18.1 ± 7 mL/kg/min; a 16% difference; $p < 0.01$).[4] Similar results have been reported by others: peak $\dot{V}o_2$ was 17%[5] or 18%[8] higher during the treadmill test vs the bicycle. Previous studies have reported a significantly higher peak heart rate[6,8] and a higher sensitivity to detect coronary ischemia with the treadmill as compared to the bicycle test.[8] However, others have reported a higher peak $\dot{V}o_2$ but no significant difference in peak heart rate when comparing several treadmill and bicycle protocols.[4] Another study[5] reported a higher peak heart rate with the treadmill as compared to the bicycle, but similar rate-pressure products due to higher BP values during the bicycle test. We do not

have data regarding rate-pressure product since major artifacts precluded reliable BP recordings at peak exercise. However, in the study[8] demonstrating a higher sensitivity for detecting myocardial ischemia by the treadmill as compared to the bicycle, the differences in rate-pressure product were mainly due to a significant difference in heart rate, whereas values for systolic BP did not differ.

The differences in peak $\dot{V}o_2$ values between the two modes were lower in the current study than previously reported among healthy subjects tested using modern bicycle and treadmill ergometers. Thus, beyond other advantages, such as lower requirements for space, less noise, and fewer artifacts, the bicycle is a viable alternative to the treadmill test. It remains to be demonstrated whether similar results exist for patients with coronary artery disease, and whether the rather small differences in peak $\dot{V}o_2$ and similar peak heart rates would account for any differences in the provocation of ST-segment changes and thus the sensitivity to detect coronary ischemia. Even if the treadmill test might by slightly superior in inducing ischemia and ST-segment changes, this might be balanced by the lower degree of artifacts caused by the bicycle compared to the treadmill.

Predicted vs Measured Exercise Capacity for the Treadmill Test

The correlation coefficients between the pretest estimates of exercise capacity (METs nomogram) and both estimated METs (0.59) and measured METs (0.50) were lower than previously reported values for the treadmill protocol (0.76 and 0.56, respectively).[14] Similar to a previous study[14] using the treadmill, the median METs nomogram level we observed (15 METs) was comparable to the subsequently achieved median measured METs (14.2 METs, a 6% difference) despite a statistically significant difference between the two values. Therefore, the value for METs nomogram provides a rough estimate of peak $\dot{V}o_2$ (METs nomogram multiplied by 3.5) prior to beginning the exercise test. As previously shown for the treadmill, METs nomogram, PAS, and age were significant pretest predictors of measured exercise capacity expressed as measured METs.

Estimated vs Measured Exercise Capacity for the Bicycle Test

Exercise capacity as estimated from the resistance on the bicycle clearly overestimated measured METs. However, the correlation between measured METs (as derived from peak $\dot{V}o_2$ by division by 3.5)

and estimated METs was particularly high (correlation coefficient, 0.90). Since peak $\dot{V}o_2$ assessment with gas exchange techniques requires more time and equipment and is not available in many laboratories, a reliable method to estimate peak $\dot{V}o_2$ and thus measured METs is useful. Several equations are commonly used to determine measured METs: body weight-corrected bicycle work capacity (watts/kilogram) $\times$ 3.85 (equation 4); or body weight-corrected bicycle work capacity (watts/per kilogram) $\times$ 3.486 + 1 (derived from equation 1).[3] The latter equation was used in the current study to convert METs nomogram into bicycle work capacity nomogram. We therefore created an equation including only those test parameters that could be easily obtained from the bicycle exercise test without gas exchange techniques. Interestingly, we found that in addition to body weight-corrected bicycle work capacity, a lower height and higher resting heart rate (ie, heart rate while sitting quietly on the bicycle) were significant predictors of peak $\dot{V}o_2$. The use of equation 4 instead of equation 3 would result in an even higher overestimation of peak $\dot{V}o_2$ as long as exercise capacity was > 2.75 W/kg. This suggests that the equation derived from the present results might be used to estimate peak $\dot{V}o_2$ based on a bicycle ramp test without gas exchange techniques in healthy subjects. However, prospective validation is needed. For application of the nomogram of course, equation 1 must be employed, since the nomogram has now been tested relying on this formula.

Study Limitations

Our data were assessed in healthy and, in the majority, young subjects and may not be applicable to older patients and those with cardiovascular disease. Age alone was not an exclusion criterion, but many more young subjects volunteered for the study. The percentage of women participating in the study was small, and therefore inferences regarding women are limited. In addition, it is unknown whether our findings can be applied to patients receiving cardiovascular medications, including β-blockers or other negative inotropes. Further studies in patients with cardiovascular disease and chronic heart failure are needed. In addition, one could criticize the use of a 3-lead instead of a 12-lead ECG. However, the ECG was most important for correct heart rate assessment rather than interpretation of ischemia. The vast majority of participants had a very low cardiovascular risk profile, and most of them were physically active and had never had any symptoms during exercise.

Conclusions

The following conclusions can be drawn for healthy European subjects with moderate-to-high working capacity undergoing bicycle exercise testing: (1) application of the modified variant of the VASQ nomogram results in a test duration from 8 to 12 min in a high percentage of subjects; (2) the differences in peak $\dot{V}O_2$ between the treadmill and bicycle were lower than previously reported in patients with coronary artery disease; and (3) peak $\dot{V}O_2$ can be roughly estimated on the bicycle using an equation adjusting estimated METs with height and resting heart rate. Thus, the bicycle is a viable alternative to the treadmill with respect to both accuracy of peak $\dot{V}O_2$ assessment and practical utility.

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