Relationships between HR and \( \dot{V}O_2 \) in the obese

NUALA M. BYRNE and ANDREW P. HILLS

School of Human Movement Studies, Faculty of Health, Queensland University of Technology, Brisbane, QLD, AUSTRALIA; and Division of Metabolism and Physiology, Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, AL.

ABSTRACT

BYRNE, N. M., and A. P. HILLS. Relationships between HR and \( \dot{V}O_2 \) in the obese. Med. Sci. Sports Exerc., Vol. 34, No. 9, pp. 1419–1427, 2002. Purpose: To enable more targeted exercise prescription for the obese, the purpose of this study was to consider relationships between relative indices of \( \dot{V}O_2 \)peak, \( \dot{V}O_R \), \( HR_{\text{peak}} \), and HRR in a sample of obese adults. In particular, the study aimed to determine whether %HRR was equivalent to %\( \dot{V}O_2 \)peak or %\( \dot{V}O_R \). A further aim was to evaluate whether the %\( \dot{V}O_2 \)peak-%HRpeak relationship defined by the ACSM holds in the obese population, or whether there is a deviation in this relationship as is noted in individuals with low functional capacity. Finally, the study aimed to determine the degree of variability in relative workload relating to lactate threshold (LT). Methods: Thirty-two sedentary obese adults, 17 women and 15 men (42.1 ± 9.6 yr, 37.4 ± 5.7 kg·m\(^{-2}\)) attended a testing session each week for 3 wk. The three sessions involved 1) familiarization with testing protocols; 2) graded treadmill tests to evaluate submaximal and peak cardiorespiratory capacity; and 3) assessment of body composition via deuterium dilution, and resting HR (HRrest) and oxygen consumption (\( \dot{V}O_2 \)rest) collected during assessment of resting metabolic rate (RMR) via a ventilated hood system. Results: The primary findings were that in the obese: 1) the %HR peak-%\( \dot{V}O_2 \)peak relationship was significantly greater than the ACSM recommendations, 2) the %HRR was equivalent with %\( \dot{V}O_R \) not %\( \dot{V}O_2 \)peak, and 3) exercise prescription at fixed percentages of \( \dot{V}O_2 \)peak or \( HR_{\text{peak}} \) corresponded with wide ranges of exercise intensities in relation to LT. Conclusions: The relationships between cardiorespiratory parameters defined in normal weight populations differ to some degree in the obese, and this has implications both for optimizing exercise intensity for weight loss and exercise adherence in obese adults. Key Words: EXERCISE PRESCRIPTION, OBESITY, SUBMAXIMAL MARKERS, LACTATE THRESHOLD, EXERCISE INTENSITY

Cardiorespiratory capacity is recognized as an important component of health-related fitness and a relevant parameter against which exercise prescription can be referenced (1). In the main, cardiovascular responses to exercise are directly proportional to oxygen demands of skeletal musculature, with oxygen uptake (\( \dot{V}O_2 \)) and heart rate (HR) increasing linearly with work rate. Given this relationship, HR is commonly used as a practical way of prescribing and monitoring exercise at specific intensities. The 1991 ACSM Position Statement recommended that apparently healthy adults exercise at intensities within 40–85% of maximal oxygen consumption (\( \dot{V}O_2 \)max), with 40, 50, 70, 80, and 85% \( \dot{V}O_2 \)max proposed to correspond with 55, 62, 70, 85, and 90% of maximal HR (HRmax), respectively. The scientific bases for these recommendations stemmed from a number of studies that utilized regression equations to determine %\( \dot{V}O_2 \)max from %HRmax (8,9,12,13,19,20). Swain and colleagues (23) proposed that the methods by which the values for %HRmax were derived are flawed. In particular, projecting target %HRmax values for a given %\( \dot{V}O_2 \)max requires that the equation be transposed. Transposition of the relationship in this way is not mathematically sound. Further, it was noted that in the foundation studies, the data from all subjects was collectively analyzed to produce a single regression for the group. Swain and Leutholtz (24) suggested that it is more appropriate to perform a linear regression for each subject and with the resulting data (slopes and intercepts), calculate target %HRmax values for each individual, from which mean group values can be determined. In undertaking such analyses on data collected from 162 apparently healthy men and women aged between 18 and 34 yr, Swain and Leutholtz (24) found the values obtained for %HRmax were significantly greater than the ACSM recommendations at all proportions of \( \dot{V}O_2 \)max. Similar inconsistencies have been noted in untrained individuals suffering from chronic obstructive pulmonary disease (COPD) where percentages of peak HR (HRpeak) at 50, 60, and 80% (but not 85%) peak aerobic capacity (\( \dot{V}O_2 \)peak) were significantly higher than ACSM recommendations (21).
Alternative approaches have been employed in the utilization of HR for prescriptive purposes. Work undertaken by Karvonen and colleagues (11) examined the HR responses of six young men to exercise training and expressed the exercise HR as a percentage of the difference between rest and maximum, since referred to as the HR reserve (HRR). Although no measures of oxygen consumption were made, the equivalency of %HRR to %VO₂max has since been widely assumed and accepted despite inconsistent findings (17,27,28). Swain and Leutholtz (24) demonstrated in a group of 63 apparently healthy young men and women aged between 18 and 40 yr that %HRR was not equivalent to %VO₂max, finding the %HRR values were significantly lower than the %VO₂peak at the same workload. In contrast, when aerobic capacity expressed as a percentage of the difference between rest and maximal values (VO₂ reserve, VO₂R) was compared with proportional HRR, no differences existed. Subsequently, the ACSM published the updated Position Statement in 1998 cognisant of these findings.

The latest Position Statement from the ACSM regarding exercise prescription to develop and maintain cardiorespiratory fitness, muscular fitness, and flexibility in healthy adults identified the following guidelines for the intensity of training: 50/65%–90% of maximum heart rate (HR max), or 40/50%–85% of maximum oxygen uptake reserve (VO₂R) or HRR reserve (HRR). Aside from work undertaken with individuals suffering from COPD, there is little evidence for the relationship between parameters of cardiovascular and aerobic capacity in populations who commonly display a low functional capacity. The current ACSM guidelines simply suggest that the lower-intensity values, that is, 40–49% of VO₂R or HRR and 55–64% of HR max, are most applicable to individuals who are quite unfit. The limited work completed with clinical populations means that a reevaluation of these relationships in populations such as the obese is warranted.

In the two studies to date that have examined the relationship between percentages of peak HRR and VO₂R, resting data were collected during 5 min of seated rest immediately before a maximal incremental cycle ergometry test (18,24), and resting HR (HRrest) measured after 30 min of seated rest (18). Given that two of the intensity prescription approaches employ percentages of HR or VO₂ reserve to investigate the relationships between these HR and VO₂ parameters accurately, inclusion of true resting values is required. Ideally, the resting data used in the calculation of HRR and VO₂R should be obtained during measurement of RMR.

Although the underlying mechanisms of the lactate threshold (LT) have been the focus of considerable academic debate, it is considered a valid physiological breakpoint or phase that reflects the workload at which the rate of lactate synthesis exceeds the rate of clearance, resulting in lactate and H⁺ accumulation (15,26). Consequently, it may correspond with the optimal exercise intensity for the obese as it may reflect the intensity of maximum energy expenditure while still being tolerable for extended periods of time (10). In a group of cyclists and triathletes, Meyer and colleagues (14) demonstrated that workload described by commonly employed training thresholds reflected wide ranges of exercise intensity as defined by LT. As a result, a reliance on certain intensities described by specific percentages of VO₂max or HR max meant some athletes were working well below, and others well above, the LT. Whether this same degree of variability is characteristic of the obese has not been reported.

To enable more targeted exercise prescription for the obese, the purpose of this study was to consider relationships between relative indices of VO₂peak, VO₂R, HR peak, and HRR in a sample of obese adult men and women. In particular, the study aimed to determine whether %HRR was equivalent to %VO₂peak or %VO₂R. A further aim was to evaluate whether the %VO₂peak-%HRpeak relationship defined by the ACSM holds in the obese population, or whether there is a deviation in this relationship as was found in chronic obstructive pulmonary disease patients. Finally, the study aimed to determine the degree of variability in relative proportions of maximal cardiorespiratory capacity at the LT.

METHODS

Subjects. Thirty-two sedentary obese adults, 17 women and 15 men (42.1 ± 9.6 yr; 37.4 ± 5.7 kg·m⁻²) were recruited for the study and gave informed written consent to participate in accordance with the University Ethics Committee guidelines. The subjects volunteered after responding to press releases on local radio and in local newspapers, and attending information evenings at the Human Movement Studies Clinic, Queensland University of Technology. Respondents were ineligible for inclusion if they were pregnant or lactating, nonambulatory, or taking medication known to affect heart rate, body composition, or electrolyte balance. Eligibility was also dependent upon being euthyroid, nondiabetic, a nonsmoker, having BMI > 30 kg·m⁻², and having been weight stable (± 2 kg) and sedentary for at least 6 months before recruitment. Sedentary was defined as no regular physical activity (<2 times per week) in the past 12 months, including work-related physical activity. Descriptive data of the subjects are presented in Table 1.

Study design. Subjects were required to attend a testing session each week for 3 wk. For each subject, the sessions were scheduled for the same time of day and day of the week to remove any influence of diurnal variations and carry-over effects of the previous testing session. The three sessions involved: 1) a treadmill test to assist in subject familiarization; the test enabled researchers to gauge working capacity and enable subjects to become accustomed with the treadmill and gas analysis apparatus; 2) a discontinuous graded treadmill test to assess cardiorespiratory function; and 3) assessment of body composition and RMR.

Study methods. Subjects reported to the University laboratory a minimum of 3 h after their last food or fluid intake, wearing light-weight, comfortable clothing, having abstained from strenuous exercise and consumption of cef-
feine, alcohol, or salty foods in the previous 12 h, and having voided a maximum of 10 min prior. Before the beginning of each treadmill test, subjects were familiarized with the Borg 6–20 scale for the rating of perceived exertion (RPE) (4) and fitted with a Hans-Rudolf headset (with two-way breathing valve and pneumotach), a nose clip, and a Polar Coded Transmitter™ (Polar Electro, Kempele, Finland). The discontinuous treadmill protocol (4-min work stages and 2-min rest periods) provided sufficient opportunities to address any subject concerns and minimize discomfort throughout the test. The mean difference between the speed indicated by the treadmill and the speed calculated by the test was derived using the equation (cycles-min⁻¹) × length of mat = m-min⁻¹ and was found to be 0.04 ± 0.01 km·h⁻¹ (0.0275 ± 0.009 miles·h⁻¹).

The age range of the subjects recruited for the study was 21–65 yr. Thus, the predicted heart rate range of 55% HRpeak to HRmax equated with approximately 70% of HRmax in five to seven stages. No single treadmill speed achieved the protocol goals with constant 2.5% increases in grade for all subjects. This is partly due to the difference in stride length of the subjects tested, whose heights ranged from 1.54 to 1.89 m, and to the differences in functional mobility. Consequently, before the familiarization test, subjects were introduced to walking on the treadmill, and at 0% grade a speed between 2 and 3.5 miles·h⁻¹ that elicited a heart rate of approximately 55%–(220 – age) was identified for each subject.

In the familiarization session, the individually defined treadmill speed remained constant throughout the test, and workload was modified by gradient increases of 2.5% for each stage, starting at 0%. On average, the workload increased by 0.5–0.875 METs (mechanical calculation) per stage. To ensure that the peak values obtained were representative of maximal capacity, the second testing session utilized the same protocol but started at a point two stages before the predicted lactate threshold for each individual. The test data were accepted provided RER equalled or exceeded 1.10 and HR was greater than 85% of predicted maximum. Three subjects were required to repeat the test as in each case one of these criteria was not met. HR was recorded every 5 s throughout the test by using a Polar Vantage™ monitor (Polar Electro), and data were transferred to a computer at the completion of each test. Respiratory gases were collected throughout the test using a Q-PLEX Gas Analysis System (Quinton Instrument Co., Seattle, WA). The O₂ and CO₂ analyzers were calibrated before each test against known gas concentrations and the flowmeter calibrated against a 3.0-L syringe. Heart rate and respiratory gases were averaged for the last 60 s of each stage, and the highest average value for 30 s in the last stage (provided RER ≥ 1.10) was recorded as the peak value.

Duplicate 0.5-mL samples of capillary blood obtained via the finger-prick method were collected immediately at the end of each work stage. Samples were collected in a capillary tube after the finger had been cleansed with an alcohol swab and punctured with a lancet, and immediately deproteinized in chilled perchloric acid and refrigerated. Blood lactate concentrations were subsequently analyzed via an ultraviolet endpoint method using the spectrophotometric assay procedure (7); 40 μL of clear supernatant was added to 2 mL of reagent, vortexed and incubated for 45 min at 37°C. The absorbance of NADH for the sample was read off a spectrophotometer using a UV lamp set at a wavelength of 340 nm. The coefficient of variation for the repeated measures was 4.3%. The LT was determined as described by Beaver et al. (2). Each blood lactate curve was divided into two data segments determined by visually identifying where the steep portion of the curve originated. The data point between the two segments (the division point) was included in both data sets. A straight line using linear regression analysis fit each data segment, and LT was identified as the intersection between these two lines. Identification of the data segments, with subject status blinded, was undertaken independently by three exercise physiologists and by the primary investigator twice. Determinations by the primary investigator were correlated with those made by the other physiologists, and the mean of these correlation coefficients was calculated for inter-investigator reliability (r = 0.92). Intra-investigator reliability was determined from a correlation analysis performed on the two determinations by the primary investigator (r = 0.99). Additionally, ANOVA revealed no significant differences among any of the tests in LT determination (P = 0.95). For each subject HR, VO₂, and RPE were plotted against workload and linear regression analyses conducted. The linear formulae were used to determine the cardiorespiratory and perceived exertion values corresponding with LT.

### TABLE 1. Subject characteristics.

<table>
<thead>
<tr>
<th>All Subjects</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N = 32)</td>
<td>(N = 15)</td>
<td>(N = 17)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>42.1 ± 1.7</td>
<td>42.5 ± 2.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>108.8 ± 3.5</td>
<td>117.1 ± 5.3</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>37.4 ± 1.0</td>
<td>37.6 ± 1.5</td>
</tr>
<tr>
<td>%BM 1.5 38.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>44.7 ± 1.5</td>
<td>38.6 ± 1.7</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>48.6 ± 2.5</td>
<td>46.1 ± 3.5</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>59.4 ± 1.3</td>
<td>70.6 ± 4.1</td>
</tr>
<tr>
<td>HRrest (beats·min⁻¹)</td>
<td>63.4 ± 2.0</td>
<td>65.5 ± 2.6</td>
</tr>
<tr>
<td>HRpeak (beats·min⁻¹)</td>
<td>170.4 ± 3.9</td>
<td>169.0 ± 4.3</td>
</tr>
<tr>
<td>VO₂rest (mL·min⁻¹·1.73 m⁻²)</td>
<td>2.61 ± 0.06</td>
<td>2.78 ± 0.10</td>
</tr>
<tr>
<td>VO₂peak (mL·min⁻¹·1.73 m⁻²)</td>
<td>4.81 ± 0.10</td>
<td>4.58 ± 0.12</td>
</tr>
<tr>
<td>VO₂peak (mL·kg⁻¹·1.73 m⁻²)</td>
<td>26.71 ± 0.91</td>
<td>30.28 ± 1.47</td>
</tr>
<tr>
<td>VO₂peak (mL·kg⁻¹·1.73 m⁻²·1)</td>
<td>49.09 ± 1.90</td>
<td>50.17 ± 2.86</td>
</tr>
<tr>
<td>a Values are means ± SEM; t-test, analyses between men and women; FFM, fat-free mass.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b P &lt; 0.05; ** P &lt; 0.01; *** P &lt; 0.001.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Measurements of body height (stretch stature) to the nearest 0.1 cm using a Harpenden stadiometer, and body weight to the nearest 5 g recorded on a digital scale, were taken. Body composition was determined from measurements of total body water (TBW) by using stable, nonradioactive, nontoxic isotope deuterium (2H2O). Subjects orally consumed a dose equating 0.05 g·kg⁻¹ body weight of 2H2O. A single urine sample was obtained before the dose and subsequently 4–6 h postdose. The enrichment of 2H2O in the predose and postdose samples was assessed using isotope ratio mass spectrometry to determine TBW (30). All assays were performed in triplicate with repeat assays in our laboratory demonstrating CV of 2.0% at low enrichment levels and 1% for higher values. TBW values were used to calculate FFM assuming a 73% hydration factor.

Resting O2 consumption (VO2rest) values were recorded during RMR assessment by using a ventilated hood system (Deltatrac II, Datex, Helsinki, Finland), which included a paramagnetic O2 sensor and an infrared CO2 analyzer, and a mass flow meter that allows for a variable flow of air through the system. Measurement of RMR with this device for the between-day testing in our laboratory is reproducible with an interindividual coefficient of variation of 2.7 ± 0.6%. Before RMR measurement, subjects rested for 45 min during a whole-body DXA scan (data not presented here). The analyzer was calibrated before each measurement with standardized gases. Directly after the DXA scan, subjects were fitted with a Polar Coded Transmitter™ (Polar Electro), and a transparent hood connected to the device was placed over the head of the subjects. After 10-min adaptation to the hood, the RMR was measured from oxygen consumption, and carbon dioxide production was analyzed continuously for 30 min. Data for the last 10 min of the measurement period was used for analyses.

Data analysis. There has been an increased recognition of the need to calculate relationships based on individual data rather than on pooled group data. Hence, analyses were undertaken for each subject, with relationships between HR, VO2, and blood lactate investigated independently then pooled to obtain mean group values. For each individual, HR and VO2 values for the end of each stage were expressed as a percentage of peak values. Linear regressions were performed for each of the 32 subjects by using the paired %HRpeak and %VO2peak data points at each workload, with %VO2peak as the independent variable. Using the slope and intercept from each individual’s regression equation, percentages of HRpeak corresponding to 40, 50, 60, 80, and 85% of VO2peak were determined for each subject. Similarly, for each individual, HR and VO2 values for the end of each stage were expressed as a percentage of HRR and VO2R, respectively.

The regression for the lactate-workload plot was undertaken using polynomial of third order (f = α0 + α1·x + α2·x² + α3·x³), and the resulting regression coefficients for individual subjects ranged between 0.97 and 0.99. The average predicted residual error sum of squares (PRESS statistic = 2.4 ± 0.4) demonstrated an acceptable level of the predictive ability of the model. The resulting formula individually served as the basis for determining the lactate concentrations corresponding to the workloads for the tested proportions of VO2peak, HRpeak, VO2R, and HRR.
RESULTS

A summary of the physiological characteristics of the subject population as a group, and for each gender separately, is presented in Table 1.

%HR_{peak} predicted from %VO_2peak. The mean (±SEM) of the 15 linear regressions from the men was: %HR_{max} = (0.643 ± 0.010)%VO_{2max} + (36.8 ± 1.0), with r = 0.988 ± 0.001; and for the 17 women: %HR_{max} = (0.628 ± 0.014)%VO_{2max} + (39.0 ± 1.3), with r = 0.977 ± 0.010. The percentages of HR_{peak} that were obtained by the subjects at designated percentages of VO_{2peak} are shown in Table 2. Student t-tests demonstrated no gender differences between the mean slopes (P = 0.75), intercepts (P = 0.77), regression constants (P = 0.19), and %HR_{peak} values at 40% (P = 0.86), 50% (P = 0.90), 60% (P = 0.95), 80% (P = 0.95), and 85% (P = 0.93) VO_{2peak} derived from the individual regression equations. Consequently, the male and female subjects could be treated as a single group.

Table 3. Intercepts, slopes, and correlation coefficient of linear regression analyses for %HRR predicted from %VO_{2peak} and %HR predicted from %VO_{R}.

<table>
<thead>
<tr>
<th>Intercept</th>
<th>Slope</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>%HRR vs %VO_{2peak}</td>
<td>-10.0 ± 0.9*</td>
<td>1.11 ± 0.02**</td>
</tr>
<tr>
<td>%HRR vs %VO_{R}</td>
<td>-0.2 ± 0.6</td>
<td>1.01 ± 0.04</td>
</tr>
</tbody>
</table>

* Differs significantly from 0 (P < 0.01); ** differs significantly from 1 (P < 0.01).
female data were pooled, for comparison with the ACSM recommendations. As shown in Figure 1, the %HRpeak values were significantly greater than those suggested by ACSM at 40%VO2peak (P < 0.001), 50%VO2peak (P < 0.001), and 60%VO2peak (P < 0.01). The discrepancy was 3–4 percentage points at 40% and 50% VO2peak and over 2 percentage points at 60%VO2peak. However, no differences existed between the individually defined regression equations and ACSM recommendations at 80 and 85%VO2peak, with mean values within 0.5–1.2 percentage points.

%VO2peak and %VO2R predicted from %HRR. As shown in Table 3, the regressions for %HRR predicted from %VO2peak did not coincide with the line of identity. The mean value of the intercept was significantly different from zero (P < 0.01). Further, the mean value of the slope differed significantly from 1 (P < 0.01). In contrast, the regressions for %HRR predicted from %VO2R were not distinguishable from the line of identity. There were no significant differences between the mean intercept and 0 or between the mean slope and 1.

There was a significant inverse relationship between fitness level (VO2peak) and the intercept of the %HRR-predicted from %VO2peak regressions when the maximal oxygen uptake was expressed relative to FFM (mL·kg−1·min−1; r = 0.43, P < 0.05), but no relationship existed when VO2peak was expressed per unit body weight (mL·kg−1·min−1; P = 0.13). To demonstrate this lack of a fitness effect when VO2peak was expressed per kilogram body weight, the %HRR predicted from %VO2peak data for subjects in the top fitness tertile (VO2peak > 52 mL·kg−1·min−1; N = 11) was plotted along with the data for the lowest fitness tertile (VO2peak < 42 mL·kg−1·min−1; N = 11) in Figure 2. There was no difference between the highest and lowest fitness tertiles for the average slopes (1.01 ± 0.01 vs 1.13 ± 0.07, P = 0.67) nor the average intercepts (−10.5 ± 1.1 vs −12.5 ± 1.4, P = 0.08). The average values for the %HRR corresponding with percentages of VO2peak and VO2R are outlined in Tables 4a and 4b, respectively.

Relative intensity at LT. Workloads at 60%HRpeak, 50%VO2peak, 90%HRpeak, and 85%VO2peak expressed as percentages of individual LT were 59.0 ± 2.8%, 74.4 ± 2.4%, 123.6 ± 1.9%, and 128.4 ± 3.0%, respectively. The relative exercise intensities corresponding with LT were 78.3 ± 6.0%HRpeak, 65.2 ± 1.6%HRR, 67.3 ± 7.7%VO2peak, and 63.4 ± 1.4%VO2R. Workloads at 60%HRpeak, 50%VO2peak, 90%HRpeak, and 85%VO2peak expressed as percentages of individual LT were 59.0 ± 2.8%, 74.4 ± 2.4%, 123.6 ± 1.9%, and 128.4 ± 3.0%, respectively (Fig. 3). The mean ± SEM (range) workloads for 60%HRpeak, 50%VO2peak, 90%HRpeak, and 85%VO2peak were 3.0 ± 0.2 (1.2–5.8), 3.8 ± 0.2 (1.5–6.7), 6.1 ± 0.2 (4.0–9.9), and 6.4 ± 0.4 (4.2–9.6) METs, respectively.

DISCUSSION

The primary findings of the current study were that in the obese: 1) the %HRpeak-%VO2peak relationship was significantly greater than the ACSM recommendations, 2) the %HRR was equivalent with %VO2R not %VO2peak, and 3) exercise prescription at fixed percentages of VO2peak or HRpeak corresponded with wide ranges of exercise intensities in relation to LT.

%HRpeak-%VO2peak relationship. Defining and monitoring exercise intensity using percentages of HRpeak is commonplace given the impracticality of using proportions of VO2peak in field situations. In the current study, it was shown that at 40, 50, and 60%VO2peak the %HRpeak values were on average 59, 65, and 72%V˙O2peak, respectively, and thus significantly greater than the ACSM recommendations. These differences may be attributed to the approach undertaken to analyze the data. The studies upon which the ACSM guidelines were based determined the relationship from linear regression analyses using %HRmax as the independent variable. Subsequent use of the linear regression equation to predict %HRmax at given proportions of VO2max is mathematically unsound. The approach undertaken in the current study was to use %VO2peak as the independent variable. Further, as outlined by Swain et al. (23), pooling the raw data to produce a single group regression eliminates individual variability from the results. Consequently, in the current study, regression analyses were performed on the data of each subject separately, and the resulting slopes and intercepts of the regression lines were used to determine each subject’s %HRpeak values at the target %VO2peak intensities. This is the first study to utilize this mathematically sound analysis approach in an obese population.

The results of the current study concur with the findings from the only other study to date to have investigated the %HRpeak-%VO2peak relationship in men and women under

### Table 4a. %HRR at indicated %VO2peak for men, women, and total group.

<table>
<thead>
<tr>
<th></th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>80%</th>
<th>85%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men (N = 15)</td>
<td>34.7 ± 1.8</td>
<td>46.0 ± 2.1</td>
<td>57.3 ± 2.4</td>
<td>80.0 ± 3.1</td>
<td>85.7 ± 3.3</td>
</tr>
<tr>
<td>Women (N = 17)</td>
<td>34.7 ± 1.2</td>
<td>45.7 ± 1.2</td>
<td>56.5 ± 1.2</td>
<td>78.8 ± 1.2</td>
<td>84.4 ± 1.2</td>
</tr>
<tr>
<td>Total (N = 32)</td>
<td>34.7 ± 1.1</td>
<td>45.9 ± 1.2</td>
<td>57.0 ± 1.3</td>
<td>79.4 ± 1.6</td>
<td>85.0 ± 1.7</td>
</tr>
</tbody>
</table>

Values are means ± SEM.

### Table 4b. %HRR at indicated %VO2R for men, women, and total group.

<table>
<thead>
<tr>
<th></th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>80%</th>
<th>85%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men (N = 15)</td>
<td>40.1 ± 1.2</td>
<td>50.2 ± 1.4</td>
<td>60.3 ± 1.6</td>
<td>80.5 ± 1.9</td>
<td>85.5 ± 2.0</td>
</tr>
<tr>
<td>Women (N = 17)</td>
<td>40.9 ± 1.6</td>
<td>50.7 ± 1.6</td>
<td>60.5 ± 1.7</td>
<td>80.0 ± 1.8</td>
<td>84.9 ± 1.8</td>
</tr>
<tr>
<td>Total (N = 32)</td>
<td>40.5 ± 1.0</td>
<td>50.4 ± 1.1</td>
<td>60.4 ± 1.3</td>
<td>80.2 ± 1.3</td>
<td>85.2 ± 1.3</td>
</tr>
</tbody>
</table>

Values are means ± SEM.
the same laboratory conditions. Swain et al. (23) investigated 162 healthy 18- to 34-yr-old men and women, and found the %HRpeak-%VO2peak relationship to be significantly higher than ACSM guidelines at 40, 60, 80, and 85%VO2max. However, there were a number of notable differences between Swain et al. (23) and the current study. In the obese population, the magnitude of discrepancy in %HRpeak at 40%VO2peak was 9%, notably lower than the 15% identified by Swain et al. (23). Further, the differences between the obese and the ACSM %HRpeak-%VO2peak relationship at 80 and 85%VO2peak was not significant. Swain et al. (23) recommended that in the apparently healthy the %HRmax values corresponding with 40, 60, 80, and 85%VO2max are 63, 76, 89, and 92%. With reference to the obese, these proportions of maximal oxygen uptake are too high. Finally, Swain et al. (23) suggested a gender difference might exist in determination of target heart rates. No differences between the %HRpeak-%VO2peak relationship of men and women was noted in the population of obese adults tested. %VO2peak and %VO2R predicted from %HRR. Very little comparative data are available on exercise intensity described as a proportion of VO2R. However, as demonstrated by numerous studies of different populations in the past, %HRmax is not equivalent to %VO2max. Further, Franklin et al. (8) showed in a group of sedentary women that cardiovascular conditioning caused a shift in the %HRmax-%VO2max regression, which resulted in a higher %HRmax at a given %VO2max. One adaptive response to cardiorespiratory conditioning is a decrease in resting heart rate (29). Consequently, an approach undertaken to account for both the proportion of HRmax not being equal to the proportion of VO2max and the influence of fitness status on this relationship is the %HRR method proposed by Karvonen and colleagues (11). Although not tested or proposed by Karvonen, the %HRR has been assumed by many to provide an equivalent exercise intensity as the same proportion of VO2max. A review of the literature by Swain and Leutholtz (24) revealed that no studies after 1957 established equivalence between %HRR and %VO2max. Although two studies provided an indirect comparison of %HRR and %VO2max with mixed results (27,28), two others reported a lack of equivalence (3,17).

In a study of nine highly trained young men during treadmill running, Davis and Convertino (5) determined that %HRR was equivalent to the same percentage of the net VO2 (referred to here as %VO2R). In a study of exercise intensity of treadmill running necessary to elicit LT, Weltman et al. (28) reported that the majority of male subjects attained LT at 85%HRR and 90%VO2max confirming the unequal relationship between %HRR and %VO2max. A study of women undertaken in the same laboratory (27) produced conflicting results with the women on average attaining LT at 55% of either HRR or VO2max. However, the purpose of these studies was not to compare the %HRR-%VO2max relationship across a range of exercise intensities, nor to investigate the %HRR-%VO2R relationship. Consequently, meaningful comparisons with the data of the current study are limited. In contrast, research on the %HRR-%VO2max relationship in elderly subjects has shown definitively that at any exercise intensity the values obtained for %HRR are lower than %VO2max (3,17).

Studies by Swain and colleagues (24,25) have demonstrated, on both cycle ergometry and treadmill exercise in healthy untrained men and women, %HRR is not equivalent to %VO2max but rather %VO2R. The findings of the current study with obese subjects concur, as the slope of the %HRR predicted from %VO2peak regression was significantly greater than 1, and the intercept was significantly less than 0. Swain and Leutholtz (24) purport that the magnitude of the error in the assumed equivalence between %HRR and %VO2max is influenced by both the fitness level of the individual and the intensity of the exercise but not gender. Similarly, in the obese population studied, the magnitude of the discrepancy was not influenced by gender, was smaller as exercise intensity increased, and was inversely related to VO2peak expressed as mL·kg FFM⁻¹·min⁻¹. It was noted in the current study, however, that the influence of fitness level on the magnitude of the discrepancy between %HRR and %VO2peak was not evident when peak aerobic capacity was expressed relative to the total body weight (mL·kg⁻¹·min⁻¹).

The findings of the current study with obese adults concur with previous research demonstrating equivalence between %HRR and %VO2R. The slope of the %HRR-%VO2R regression line was not significantly different from 1, and the intercept compared significantly with zero. However, in comparison with the few studies that have investigated the %HRR-%VO2R relationship (5,18,24,25), this is the first study to have utilized true resting values in the calculation of both HRR and VO2R. The resting VO2 and HR data in the study by Swain and Leutholtz (24) were collected 5 min before the cycle ergometry test with subjects seated on the bike, and thus cannot be considered to represent true resting conditions. In the current study, resting values for VO2 and HR were obtained from a 45-min RMR test, and thus negate any expected elevations associated with pretesting anxiety.

FIGURE 3—Mean (± SD) and ranges of relative intensities as a percentage of LT.

SUBMAXIMAL MARKERS OF EXERCISE INTENSITY

Medicine & Science in Sports & Exercise× 1425

Copyright © American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.
Relative exercise intensity at LT. This study demonstrated that exercise prescription at fixed percentages of VO$_{2\text{peak}}$ and HR$_{\text{peak}}$ corresponded with wide ranges of exercise intensity as defined in relation to LT. Consequently, relying on certain intensities described by specific percentages of VO$_{2\text{max}}$ or HR$_{\text{max}}$ some obese individuals will be working well below and others well above the LT. The relevance of this finding is dependent upon the importance placed in the LT as a submaximal marker. The LT as defined in this study reflects a breakpoint in metabolic and hormonal regulation. Although there is debate about both the approach in determining the LT and the LT concept itself, it has been thoroughly validated using endurance tests of 45- to 50-min duration (22,26). A lactate steady state was only reached in these and other studies when intensities were held at or below this threshold. Intensities 5–10% higher resulted in the accumulation of lactic acid and premature exhaustion (16). The LT can be interpreted as an individually defined maximum lactate steady state, and the intensity preceding unbalanced increases in blood lactate and H+ as the rate of synthesis exceeds the body’s capacity buffer or oxidize the substrate (15,22). The physiologic alterations associated with lactate accumulation (metabolic acidosis, impaired muscle contractility, hyperventilation, and altered oxygen kinetics) contribute to impairment of work capacity (15). Working at intensities above this threshold also results in unbalanced increases in adrenalin and noradrenalin, reflecting elevated sympathetic nervous system activity (26), a precursor to neuromuscular fatigue.

In the current study of obese adults, exercise intensities defined by 50%VO$_{2\text{peak}}$, 60%HR$_{\text{peak}}$, 90%HR$_{\text{peak}}$, and 85%VO$_{2\text{peak}}$ equated with LT-related intensity ranges of 55, 50, 44, and 38%, respectively. Presented another way, prescribing exercise intensity for the obese at 50%VO$_{2\text{peak}}$ would result in subjects working at between 38 and 88% of their individually defined optimal exercise intensity for energy expenditure at a tolerable workload (LT). Similarly, exercise prescribed at 90%HR$_{\text{peak}}$ would require the obese subjects to be working from optimal (100%, that is LT) to 44% above optimal (144% LT). Exercise at an intensity equating LT is on average 78 ± 6%HR$_{\text{peak}}$, 65 ± 2%HR, 67 ± 8%VO$_{2\text{peak}}$, and 63 ± 1%VO$_{2\text{R}}$. Thus, the degree of variability in defining the exercise intensity equating with LT is greater when defined relative to peak values (HR$_{\text{peak}}$ and VO$_{2\text{peak}}$) rather than reserve values (HRR and VO$_{2\text{R}}$). Further, as evidenced by the range of exercise intensities defined by %HR$_{\text{max}}$ and %VO$_{2\text{max}}$, the degree of variability is greater at lower intensities, the level commonly prescribed for the obese. It could be argued from these findings that many studies designed to determine the influence of exercise, defined as a proportion of peak or maximal cardiorespiratory capacity, on health and performance have been limited by the inherent degree of variance in the actual relative exercise intensity that has been prescribed.

These findings are in agreement with other studies of both trained and untrained individuals (6,14,27,28). Meyer et al. (14) reported a variability of over 30% at 75%VO$_{2\text{max}}$ in trained cyclists and triathletes. Thus, in the obese, as for all other populations tested, percentages of peak oxygen uptake and HR correspond with wide ranges of exercise intensity as defined by individual LT and should not be used as the sole determinants to define exercise intensities for training and research purposes. Individual determination of exercise intensity will ensure a more targeted and thus effective approach for exercise prescription.

Address for correspondence: Nuala M. Byrne, Ph.D., University of Alabama at Birmingham, Department of Nutrition Sciences, Division of Physiology and Metabolism, Webb Nutrition Sciences Building, Room 441, Birmingham, AL 35294-3360; E-mail: byrnen@shr.uab.edu or a.hills@qut.edu.au.

REFERENCES


