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Use of Heart Rate Reserve and Rating of Perceived Exertion to Prescribe Exercise Intensity in Diabetic Autonomic Neuropathy

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OBJECTIVE — Individuals with diabetic autonomic neuropathy (DAN) exhibit an increased resting heart rate but depressed maximal heart rate. Thus, the purpose of this study was to examine the validity of using either percent of heart rate reserve (HRR) or a rating of perceived exertion (RPE) scale to prescribe exercise intensity in diabetic individuals both with and without DAN.

RESEARCH DESIGN AND METHODS — The subjects consisted of 23 individuals with type 2 diabetes, ages 45–75 years, with (DAN; $n = 13$) or without (No DAN; $n = 10$) clinical signs of DAN, as assessed by heart rate variability using the expiration-to-inspiration ratio of the R-R interval. Peak aerobic capacity was determined using a graded protocol on a cycle ergometer, with RPE, heart rate, and $V\text{O}_2$ values recorded at each stage.

RESULTS — The subjects were similar with the exception of depressed autonomic function in DAN subjects. Peak respiratory exchange ratio values were significantly higher ($P < 0.05$) in the DAN group (1.08 ± 0.02 vs. 1.02 ± 0.01 in No DAN subjects), although DAN subjects exhibited a significantly lower ($P < 0.05$) peak exercise heart rate. A similarly highly linear relationship between %HRR and percent $V\text{O}_2$ reserve ($V\text{O}_2$R) existed for both groups ($r = 0.98$). A similar slightly weaker relationship ($r = 0.94$) was found between RPE and %$V\text{O}_2$R.

CONCLUSIONS — In conclusion, in diabetic individuals, %HRR provides an accurate prediction of %$V\text{O}_2$R and can be used to prescribe and monitor exercise intensity, regardless of the presence of DAN. The RPE scale is also a valid, albeit slightly less accurate, method to monitor exercise intensity in diabetic individuals.

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Until recently, the linear relationship between the percent of heart rate reserve (HRR) and percent of maximal aerobic capacity ($V\text{O}_{2\text{max}}$) led to the use of %HRR to quantify a given percentage of $V\text{O}_{2\text{max}}$. Recent studies in healthy adults, however, have shown that the two were not equivalent—rather that %HRR is equivalent or more closely related to the percent $V\text{O}_2$ reserve ($V\text{O}_2$R) (i.e., a percentage of the difference between resting and maximal $V\text{O}_2$ at which an individual is exercising) than to %$V\text{O}_{2\text{max}}$ (1,2). These findings led the American College of Sports Medicine to adopt %$V\text{O}_2$R in place of %$V\text{O}_{2\text{max}}$ for the prescription of exercise intensity, which in normal individuals is now generally prescribed as a percentage of maximal heart rate (60–90%), $V\text{O}_2$R (50–85%), or HRR (50–85%) (3,4). An alternate method of prescribing intensity is with the rating of perceived exertion (RPE) scale (5), which uses a subjective rating from 6 to 20 to quantify an individual's perceived exercise intensity.

Individuals with diabetic autonomic neuropathy (DAN) do not have a normal hemodynamic response to exercise. Autonomic neuropathy interferes with normal heart rate regulation during exercise by depressing maximal heart rate and blood pressure and at rest by increasing resting heart rate (6,7). Such individuals exhibit a lower peak heart rate response, lower peak plasma epinephrine, and lower plasma norepinephrine immediately after exercise, indicative of an altered sympathoadrenal response to physical activity (8). In addition, maximal aerobic capacity ($V\text{O}_{2\text{max}}$) has been shown to be lesser in some type 2 diabetic individuals both with and without DAN (9–12).

Given the abnormal hemodynamic responses seen in DAN, the American College of Sports Medicine recommends the use of the RPE scale in lieu of %HRR or percentage of maximal heart rate for prescribing exercise intensity in individuals with DAN (13). However, neither the RPE scale nor the use of HRR has been validated in the diabetic population. Therefore, the purpose of the present study was to examine the validity of using either %HRR or RPE as the equivalent of %$V\text{O}_2$R to prescribe and monitor exercise inten-

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Abbreviations: DAN, diabetic autonomic neuropathy; E:I ratio, inspiration-to-expiration ratio of the R-R interval; HRR, heart rate reserve; RER, respiratory exchange ratio; RPE, rating of perceived exertion; SEE, standard error of the estimate; $V\text{O}_{2\text{peak}}$, peak aerobic capacity; $V\text{O}_2$R, $V\text{O}_2$ reserve.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

Table 1—*Characteristics of resting subjects*

	DAN	No DAN	*P*
n (M/F)	13 (8/5)	10 (6/4)	—
Age (years)	62.9 ± 2.8	58.0 ± 2.2	0.20
Height (cm)	170 ± 2.9	173 ± 3.7	0.49
Weight (kg)	88.3 ± 5.8	94.8 ± 4.0	0.39
BMI (kg/m^2)	30.5 ± 1.5	31.9 ± 1.7	0.53
E:I ratio	1.05 ± 0.01	1.24 ± 0.04	<0.001
Fasting glucose (mmol/l)	7.06 ± 0.73	5.83 ± 0.47	0.22
$V\text{O}_2$ (ml · min^{-1} · kg^{-1})	2.9 ± 0.4	2.9 ± 0.4	0.89
Heart rate (bpm)	80 ± 4	75 ± 6	0.48

Data are means ± SE unless otherwise indicated.

sity in a type 2 diabetic population both with and without DAN.

RESEARCH DESIGN AND METHODS

— Subjects of both sexes and all ethnicities were recruited using the database of patients available at the Strelitz Diabetes Research Institute and locally distributed flyers and notices. The testing and assessments for this project took place at Old Dominion University and Eastern Virginia Medical School, both located in Norfolk, Virginia. The subjects were individuals with type 2 diabetes, ages 45–75 years, divided into two groups: those without DAN (No DAN; $n = 10$) and those with DAN (DAN; $n = 13$). Potential subjects with known cardiovascular disease, severe peripheral neuropathy, unstable proliferative retinopathy, end-stage renal disease, or uncontrolled hypertension were excluded from participation. During participation in exercise testing, all subjects continued to take their normal medications; two DAN subjects were using β-blockers that lowered their resting and exercise heart rates.

Heart rate variability with deep breathing using the inspiration-to-expiration ratio of the R-R interval (E:I ratio) was used to evaluate systemic (vagal) autonomic function (14). To complete this testing procedure, subjects were asked to wear standard electrocardiogram electrodes during deep breathing (six breaths per minute). Heart rate variance was recorded using an Anscore device (Boston Medical Technologies, Wakefield, MA) as the longest R-R interval (in milliseconds) during expiration divided by the shortest R-R interval during inspiration. The average of six of these individuals' ratios was used as the final ratio.

Resting measures of heart rate and oxygen uptake ($V\text{O}_2$) were recorded after each subject had sat quietly in a chair for 10 min to replicate a typical state of rest that could be easily reproduced in a clinical setting, as has been previously reported (1,2). All subjects had fasted overnight before testing and had abstained from vigorous exercise for at least 24 h. Peak aerobic capacity ($V\text{O}_{2\text{peak}}$) was then determined using an incremental exercise protocol on a cycle ergometer (Monark 828e). After familiarization with the cycle ergometer, subjects were fitted with a facemask and head strap. The testing protocol began with subjects cycling at 50 rpm at an external power of 0 W for the first 3 min for females (20 W for males), with 20-W increments occurring every 3 min thereafter until test termination. An online open indirect calorimetry system (K4b^{2}Portable Metabolic System; Cosmed, Rome, Italy) was used to measure and record $V\text{O}_2$, expired minute ventilation, and respiratory exchange ratio (RER) at rest and during the exercise test. Heart rate throughout the testing was monitored using a Polar heart rate monitor along with 12-lead electrocardiogram recordings taken at each stage. Blood samples were obtained at the end of each stage via fingerstick, and blood was assayed using a glucose and lactate analyzer (YSI 2300; Yellow Springs Instruments, Yellow Springs, OH). All tests were terminated at the point of the subjects' volitional fatigue (indicated by hand gesture). $V\text{O}_{2\text{peak}}$ was determined as the highest oxygen uptake averaged over 30 s during the final stage of exercise testing.

Only those tests in which the subject achieved a plateau in oxygen consumption and/or an RER of ≥1.0 were included in the analyses; this minimum RER was used to allow for the decreased maximal exercise capacity that has been reported in obese individuals with BMIs similar to the subjects in the current study (15,16). HRR and $V\text{O}_2$R were calculated by subtracting resting heart rate or $V\text{O}_2$ values from their respective peak values; accordingly, for each stage of exercise, the increment above resting for each value was divided by the calculated reserve and multiplied by 100 to get %HRR or %$V\text{O}_2$R.

Statistical analyses were completed using *t* tests (two-tailed) to compare differences between group means and using Pearson product-moment correlational analysis to determine the relationship between %$V\text{O}_2$R and %HRR or RPE for each subject. In addition, *t* tests were used to determine whether the mean slope and *y*-intercept for each group differed from the line of identity (slope = 1 and *y*-intercept = 0). The α level was set at $P < 0.05$.

RESULTS

— Resting characteristics of the subjects before exercise are presented in Table 1. Subjects in both groups were similar in all respects with the exception of E:I ratio, which was significantly depressed in the DAN group. These values were also significantly lower in comparison to age-dependent values in the normal population (17).

The subjects' responses during peak exercise are presented in Table 2. A trend ($P = 0.11$) for a lower $V\text{O}_{2\text{peak}}$ was evident in the DAN subjects. Evidence of true maximal effort was somewhat lacking in many of the subjects in both groups because only 7 of 23 achieved a plateau in $V\text{O}_2$ (5 DAN and 2 No DAN subjects), although others reported that a plateau is not necessary for attainment of $V\text{O}_{2\text{max}}$ (16). Peak RER was significantly higher ($P < 0.05$) in the DAN group than in the No DAN group, although DAN subjects exhibited a significantly lower ($P < 0.05$) peak exercise heart rate. Data from an equivalent number of DAN and No DAN subjects (four and five, respectively) were excluded before analyses were performed after subjects failed to meet the criteria of attaining a plateau in $V\text{O}_2$ and/or a peak RER >1.0.

A highly linear relationship ($r = 0.98$) between %HRR and %$V\text{O}_2$R was evident, as illustrated in Fig. 1. No significant difference between the mean regressions (slope and *y*-intercept) for DAN and No DAN subjects was evident;

Table 2—*Subjects' responses to peak cycle ergometer exercise*

	DAN	No DAN	*P*
V_{O_2} (ml · min^{-1} · kg^{-1})	15.1 ± 1.3	19.0 ± 2.1	0.11
RPE	17.1 ± 0.7	16.7 ± 0.8	0.73
RER	1.08 ± 0.02	1.02 ± 0.01	0.04
Heart rate (bpm)	131 ± 4	146 ± 6	0.04
Lactate (mmol/l)	3.8 ± 0.3	4.1 ± 0.4	0.52

Data are means ± SE.

thus, data from both subject groups were combined. For all subjects, the mean slope was 0.98 ± 0.01, the mean *y*-intercept was −2.6 ± 1.7, and the mean correlation coefficient was 0.98 ± 0.01. The slope and *y*-intercept were not significantly different from 1.0 and 0, respectively (i.e., the regression line was not different from the line of identity for %HRR and %V_{O_2}R).

Figure 2 shows the highly linear relationship (r = 0.94) between RPE and %V_{O_2}R. Data from both subject groups were again combined because no significant difference between the mean regressions for DAN and No DAN subjects was detectable. For all subjects, the mean slope was 0.11 ± 0.01, the mean intercept was 5.3 ± 0.2, and the mean correlation coefficient was 0.94 ± 0.02. Assuming that a value of 6 on the RPE scale represents rest and 20 represents maximal effort, the expected regression line would have a slope of 0.14 and an intercept of 6.0. However, the mean slope and mean intercept were both significantly different ($P < 0.001$) than these values, as shown in Fig. 2.

If the relationships between either %HRR or RPE and %V_{O_2}R are to be used in exercise prescription, it would be useful to reverse the dependent and independent variables so that the %HRR or RPE can predict the desired %V_{O_2}R. Doing so with all subject data grouped together (to allow the calculation of a standard error of the estimate [SEE]) provides the following regression equations: %V_{O_2}R = 0.95 (%HRR) + 6.8, with r = 0.95 and SEE = 10.6%V_{O_2}R units, and %V_{O_2}R = 7.14 (RPE) − 25.1, with r = 0.87 and SEE = 16.9%V_{O_2}R units. The SE for each individual subject was significantly smaller than the SEE for the group.

CONCLUSIONS — This study examined the relationship between V_{O_2}R and HRR in diabetic individuals with and without clinical DAN. We have demonstrated that %HRR is an excellent indicator of %V_{O_2}R in individuals with diabetes, regardless of the presence of autonomic neuropathy. This finding is consistent with findings for healthy adults (1,2) and cardiac patients (18). Furthermore, a significant, but less strong, relationship between RPE and %V_{O_2}R was also demonstrated in both groups of diabetic subjects.

Previous exercise recommendations have been based on the assumption that DAN would interfere with the heart rate response to exercise to such a degree as to reduce the utility of heart rate or HRR as methods for prescribing exercise intensity. To the contrary, in the present study, we demonstrated that although peak heart rate was depressed in subjects with DAN, as has been found previously (6,7), a linear relationship between %HRR and %V_{O_2}R was nevertheless retained and that this relationship was indistinguishable from the line of identity. Our findings are similar to those of Brawner et al. (18) in cardiac patients; they found that the %HRR versus %V_{O_2}R relationship was consistent with the line of identity for cardiac patients with or without β-adrenergic blockade therapy. In our subjects, however, as in cases of β-blockade use, it is important to accurately determine each subject's resting and peak or maximal heart rates rather than using estimates (maximal values are usually estimated in a normal population as 220 − age or 208 − 70% of age); the maximal value may be overestimated and resting heart rate underestimated due to the effects of DAN on these heart rate measures.

An alternative method for prescribing exercise intensity in a diabetic population, the RPE scale, is a subjective tool that may be used in place of heart rate, and its use has been the recommendation for patients with DAN (13). In normal populations, use of the RPE scale has been validated for level treadmill running (19) and during incremental exercise on a cycle ergometer (20,21). The current study found a highly linear relationship between RPE and %V_{O_2}R, providing support for its continued use by diabetic individuals. However, we found that the SEE for this relationship was not as good as the SEE for %HRR versus %V_{O_2}R. Moreover, the RPE values recorded in this study were lower than expected, most likely because some subjects may not have attained true maximal efforts.

Admittedly, it can be difficult to elicit true maximal efforts from patient populations, especially DAN patients who may be limited by symptoms. In diabetic individuals with DAN who are otherwise asymptomatic, DAN is a good predictor of major cardiac events (22) and the risk for cardiac-cerebrovascular events is high (8,22). Such individuals exhibit an abnormal left ventricular response to isometric and dynamic exercise that is due to a de-

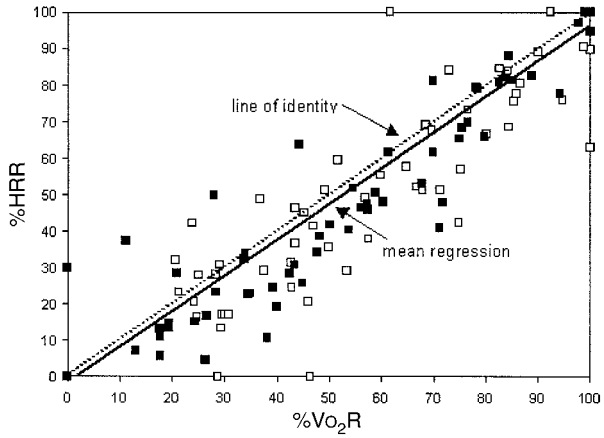

Figure 1—*Relationship between %HRR and %V_{O_2}R in DAN (□) and No DAN (■) subjects with mean regression line [%HRR = 0.98 (%V_{O_2}R) − 2.6; mean* r *= 0.98] and line of identity.*

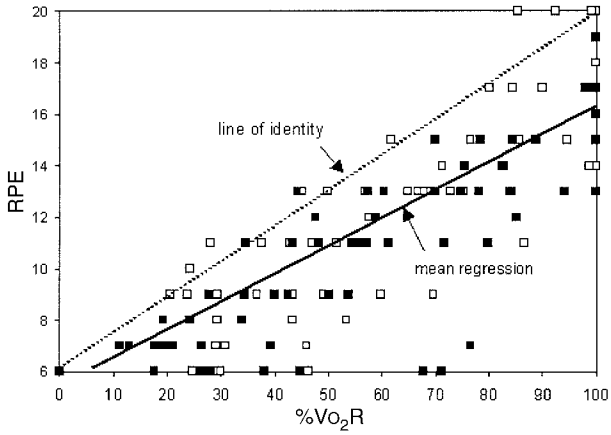

Figure 2—*Relationship between RPE and %VO_2R in DAN (□) and No DAN (■) subjects with mean regression line [RPE = 0.11 (%VO_2R) + 5.3; mean* r *= 0.94] and line of identity.*

fective inotropic recruitment, despite the presence of a normal left ventricular contractile reserve (23). Furthermore, as noted previously, obese subjects such as the ones in this study have often been reported to attain lower heart rates and RER values during maximal efforts (15,16).

In recognition of these potential risks and limitations of the subject population, the criteria for maximal effort in the present study were established as the attainment of a plateau in oxygen consumption or an RER value of at least 1.0. A value of 1.10 is often used in studies with nonpatient groups (1,2), but only six of our subjects actually reached that standard; seven subjects attained a plateau in VO_2, whereas three other subjects attained both a plateau in VO_2 and an RER of at least 1.10. In addition, the use of a cycle ergometer rather than a treadmill resulted in VO_{2peak} rather than VO_{2max}. Thus, one possible interpretation of our data is that the RPE values reported in this study are low simply because many of the subjects decided to stop their incremental exercise tests before reaching a true maximum effort. Doing so, however, would not affect the %HRR-%VO_2R relationship because that regression used peak values for both variables as the end points of the regression.

Another potential complication exists with regard to the interpretation of our RPE data. Some of the subjectivity involved in determining an RPE rating for a given exercise workload depends on the normal functioning of the sympathetic nervous system (e.g., lactate accumulation from muscle glycogen release or sweating responses). Individuals with DAN may not experience some of these usual symptoms associated with workloads of increasing intensity. In another study involving incremental exercise by individuals with diabetes on a cycle ergometer, heart rate, systolic blood pressure, norepinephrine, and epinephrine increases were most severely blunted in individuals with both parasympathetic and sympathetic damage to the autonomic nervous system (10). In our study, however, only parasympathetic DAN was assessed with the use of the E:I ratio, and peak lactate was similar in both diabetic groups, suggesting that the utility of our RPE measurements was not compromised.

In conclusion, we have demonstrated that in diabetic individuals, %HRR provides an accurate prediction of %VO_2R and can be used for this population to prescribe and monitor exercise intensity, regardless of the presence of DAN; as such, it should preferably be the method used. As an alternate, albeit slightly less accurate, method, RPE can be used to monitor exercise intensity in diabetic individuals and may be useful in clinical settings where maximal or peak heart rate is not easily measured and %HRR is therefore not routinely used.

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