Cardiovagal Modulation and Efficacy of Aerobic Exercise Training in Obese Individuals

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1Integrative Physiology Laboratory, Department of Kinesiology and Nutrition, University of Illinois at Chicago, Chicago, IL; 2Department of Physiology, Georgia Regents University, Augusta, GA; 3Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign, Urbana, IL; and 4Department of Nutrition and Exercise Physiology, University of Missouri, Columbia, MO

ABSTRACT

BAYNARD, T., S. GOULOPOULOU, R. F. SOSNOFF, B. FERNHALL, and J. A. KANALEY. Cardiovagal Modulation and Efficacy of Aerobic Exercise Training in Obese Individuals. Med. Sci. Sports Exerc., Vol. 46, No. 2, pp. 369–375, 2014. Type 2 diabetes (T2D) is associated with poor exercise tolerance and peak aerobic capacity (VO2peak) even when compared to obese nondiabetic peers. Exercise training studies have demonstrated improvements in VO2peak among patients with T2D, yet there is a large amount of variability in this response. Recent evidence suggests that cardiac autonomic modulation may be an important factor when considering improvements in aerobic capacity. Purpose: This study aimed to determine the effects of a 16-wk aerobic exercise program on VO2peak in obese individuals, with and without T2D, who were classified as having either high or low cardiovagal modulation (HCVM or LCVM) at baseline. Methods: Obese individuals (38 women and 19 men; body mass index = 36.1 kg·m−2) were studied in the fasted state. ECG recordings were obtained while seated for 3 min, before and after 4 months of exercise training (4 d wk−1, 65% VO2peak). The ECG recording was analyzed for HR variability in the spectral domain. Groups were split on a marker of CVM (normalized high frequency (HFnu)) at the 50th percentile, as either HCVM or LCVM. Results: VO2peak only increased with exercise training among those classified as having HCVM, regardless of diabetes status (T2D: HCVM = 20.3–22.5 mL·kg−1·min−1, LCVM = 24.3–25.0 mL·kg−1·min−1; obese nondiabetics: HCVM = 24.5–26.3 mL·kg−1·min−1, LCVM = 23.1–23.7 mL·kg−1·min−1) (P < 0.05). No change in VO2peak was observed for the LCVM group. Changes in weight do not explain the change in VO2peak among the HCVM group. Glucose tolerance only improved among the LCVM group with T2D. Conclusions: Obese individuals, with or without T2D, when classified as having relatively HCVM before exercise training, have a greater propensity to improve VO2peak after a 16-wk aerobic training program. Key Words: AEROBIC CAPACITY, EXERCISE TRAINING, CARDIOVAGAL MODULATION, HR VARIABILITY, OBESITY, TYPE 2 DIABETES

Exercise intolerance is common in individuals with type 2 diabetes (T2D), manifested as low levels of cardiovascular fitness (VO2peak) and described in a recent review by Reusch et al. (29). This low exercise capacity is associated with both cardiovascular and all-cause morbidity and mortality in this population (39). Despite a marked decrease in the prevalence of cardiovascular disease in the general population, diabetes-related cardiovascular mortality is three to five times higher than in populations without diabetes (29,36). Despite aggressive risk factor reduction, higher mortality rates persist in individuals with T2D, which may in part be due to low cardiovascular fitness (29).

Low VO2peak levels are mediated by a number of factors (26,29), including insulin resistance, oxidative stress, metabolic dysfunction, endothelial dysfunction, diastolic dysfunction, low cardiac perfusion, and peripheral muscle dysfunction. In essence, in the presence of a disrupted metabolic environment, as is the case often with obesity and/or T2D, this leads to cardiac, endothelial, and skeletal muscle dysfunction, all of which are important determinants of either oxygen utilization and/or delivery, thus contributing to reduced exercise capacity, even when groups are matched on physical activity/sedentary behavior and level of obesity (29).

Recent evidence suggests that cardiac autonomic regulation may play an important role in exercise tolerance (11,12,16). VO2peak is strongly associated with cardiac autonomic function in cross-sectional studies (2,4,5,9,28,34). Endurance exercise training also improves cardiac autonomic control, as primarily manifested by increases in cardiovagal modulation (CVM) (10). HR variability (HRV) has also been successfully used to individually tailor the exercise prescription based on vagal modulation to produce greater improvements in VO2peak than traditional exercise prescriptions (16,17). In addition, baseline levels of vagal modulation are associated with improved training-induced benefits in athletes (12).
Individuals with T2D exhibit poor autonomic control (manifested a low vagal and high sympathetic modulation) compared to their nondiabetic peers, and this is associated with poor cardiovascular fitness in this population (15,38). Autonomic control is also negatively affected by reduced glucose tolerance and insulin insensitivity (37), and both glucose tolerance and insulin insensitivity are associated with $\dot{V}_O_{2peak}$ (29). Furthermore, in a diabetic rat model, exercise training improved mitochondrial protein expression in control animals but not in diabetic rats (19). Considering individuals with T2D have low levels of cardiovascular fitness and HRV, they may have more difficulty improving fitness (as a result of reduced effect of training on mitochondria) compared to persons without T2D (29). Thus, it is possible that autonomic dysfunction, often manifested as low HRV, affects fitness differently in obese persons with and without T2D. Consequently, persons with T2D, with low HRV at baseline, may not have the propensity to improve their aerobic capacity following a standard training program and therefore may not improve their risk profile to the same extent as someone with T2D with higher baseline HRV. Yet, to our knowledge, it is unknown if baseline (e.g., pretraining) cardiac vagal modulation affects the effect of an aerobic training program on $\dot{V}_O_{2peak}$ in persons with T2D. Therefore, understanding the effect of exercise training in groups of obese individuals with and without T2D is important to further our appreciation of factors related to exercise tolerance.

The purpose of this study was to determine the effects of a 16-wk aerobic exercise program on $\dot{V}_O_{2peak}$ in obese individuals with and without T2D who were classified as having either high or low CVM (HCVM or LCVM) at baseline. We hypothesized that 1) $\dot{V}_O_{2peak}$ would not increase among diabetics classified as having LCVM, but would increase among obese individuals classified as having LCVM; and 2) $\dot{V}_O_{2peak}$ would increase among individuals classified as having HCVM, regardless of diabetic status.

**METHODS**

**Participants.** We conducted a retrospective analysis on the effects of training-induced changes in exercise tolerance, anthropometrics, and HRV in 59 obese individuals who completed the study (7). Training-induced changes were examined with individuals classified as having HCVM or LCVM. Two individuals were excluded as outliers (>3 SD from the mean), thus 57 individuals were included in the current analyses (Table 1). Self-reported T2D status was confirmed with either a glucose tolerance test or prescribed medications. Goulopoulou et al. (7) provided further details on the methodology presented below. All subjects were between 40 and 60 yr of age and had a body mass index (BMI) $>$30 kg·m$^{-2}$. Subjects self-reported a sedentary lifestyle for a minimum of 6 months before enrolling in this study. Perimenopausal women were excluded, and all premenopausal women were tested in the first 10 d of their menstrual cycle. Subjects were also excluded if they had self-reported overt cardiovascular disease or if they exhibited evidence of

| TABLE 1. Anthropometric, glucose tolerance, and HRV measurements before (pre) and after (post) training (16-wk aerobic exercise training) among individuals either with or without T2D, classified retrospectively as having LCVM or HCVM. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | T2D             |                |                |                |
|                | LCVM            | HCV            | LCVM            | HCV            |
| n               | 10              | 11             | 17             | 19             |
| Male/female     | 3/7             | 2/9            | 7/10           | 7/12           |
| Age (yr)        | 50±5            | 48±4           | 50±6           | 48±5           |
| Anthropometrics |                |                |                |                |
| Weight (kg)     | Pre 108.5±26.0  | Post 109.2±25.8| Pre 103.9±22.5*| Post 109.3±25.8|
| BMI (kg·m$^{-2}$) | Pre 35.5±6.3   | Post 35.7±6.4  | Pre 39.4±5.1   | Post 38.6±5.6*|
| Waist (cm)      | Pre 115.8±12.0  | Post 115.1±12.6| Pre 124.8±17.1 | Post 118.2±17.9*|
| Body fat (%)    | Pre 37.7±5.8    | Post 37.8±6.0  | Pre 47.5±6.0   | Post 47.3±6.8  |
| Glucose tolerance | Pre 2702±674   | Post 2396±600***| Pre 345±1.79   | Post 5.03±3.12  |
| Glucose AUC$^*$ (mmol·L$^{-1}$·min$^{-1}$) | Pre 2392±762 | Post 1570±209 | 1378±254 |
| Whole-body insulin sensitivity | Pre 6.77±4.30* | Post 5.40±3.24***| Pre 6.70±3.70* | Post 4.71±2.89 |
| HRV             |                |                |                |                |
| LF$_{HF}$       | Pre 5.10±1.20   | Post 5.13±1.04 | Pre 4.82±0.85  | Post 5.46±0.76 |
| HF$_{HF}$       | Pre 4.68±1.66  | Post 5.24±0.87*| Pre 5.63±1.14  | Post 5.44±0.72*|
| HR$_{peak}$     |                |                |                |                |
| HR (bpm)        | Pre 174±12      | Post 171±12    | Pre 167±7      | Post 167±9     |
|                 |                |                | 172±12         | 170±13         |

Data are mean ± SD.  
$^*$P < 0.05, time effect (before vs after training), within respective HRV status.  
$^*^*$P < 0.05, baseline differences between T2D and obese nondiabetic groups.  
**P < 0.05, time (before vs after training) by group (T2D vs obese nondiabetic) effect, within respective HRV status.

BMI, body mass index; HCVM, high cardiovagal modulation; HRV, heart rate variability; LCVM, low cardiovagal modulation; ln, natural log transformation; T2D, type 2 diabetes.
myocardial ischemia during the stress test. Subjects were also excluded if they self-reported peripheral neuropathy, tobacco use, insulin therapy, oral contraceptives, β-blocker, and glucocorticoids medications for chronic pulmonary, cardiac, or other systemic diseases. Written informed consent was obtained from each volunteer before participation in the study. This study was approved by the Syracuse University and State University of New York at Upstate Medical University Institutional Review Boards.

**Study design.** Subjects completed two testing visits before and two visits after the 16-wk aerobic exercise intervention. During visit 1, all subjects completed a physician-supervised walking treadmill protocol to determine VO₂peak. Visit 2 was completed within 2 wk of their treadmill tests, and subjects arrived at the laboratory at 0700 h after a 12-h overnight fast for measurements of resting HRV, as well as a glucose challenge test and body composition measurements. For visit 2, subjects refrained from caffeine for 12 h and alcohol and exercise for 24 h before testing. Subjects then participated in a 16-wk combination supervised and home-based aerobic exercise intervention. After the training period, the same testing visits were repeated for postmeasurements. Medication use and dose was not changed during the study period. Subjects were also instructed to maintain their normal dietary patterns.

**Aerobic exercise intervention.** Subjects participated in a 16-wk combined supervised/home-based aerobic exercise program. Subjects were instructed to walk 4 d wk⁻¹ at 65% of VO₂peak for 30 min. The duration of exercise was slowly increased over a 2 wk period at the half-way point (9 wk), so that all subjects were exercising 45 min d⁻¹ during weeks 11–16. Of the 4 d of prescribed walking, subjects reported to the laboratory 1 d wk⁻¹ for their one-on-one supervised exercise session on a treadmill. The researchers were able to accurately monitor the subjects’ workload and make adjustments as necessary during the in-person visits. HR and RPE were used to monitor the intensity of each workout. Exercise logs were maintained, and any exercise-related issues were discussed thoroughly on a weekly basis. Compliance was ~90% (14).

**HRV.** After 20 min of supine rest, continuous R-R intervals were recorded (Biopac MP100, Santa Barbara, CA) during an additional 5 min of supine rest with a modified CM5 ECG lead at a sampling rate of 1000 Hz. To control for the respiratory influence on HRV, breathing was paced at 12 breaths per minute using a metronome. The R-R intervals were analyzed using Heart Software (Oulu, Finland) as previously described (1,7,13). Low-frequency (LF; range = 0.04–0.15 Hz) and high-frequency (HF; range = 0.15–0.40 Hz) spectral power were determined using an autoregressive model (order of 10) following previous recommendations (33). Further, LF and HF were as log-transformed values.

To classify our groups as having HCVM or LCVM at baseline, the HF component of the HRV analysis was used in determining the 50th percentile split (LCVM < 50th percentile > HCVM; Table 1).

**Blood analyses.** Glucose concentrations from the oral glucose tolerance test (75-g dextrose beverage, with blood sampling every 30 min over 4 h) were analyzed using whole blood samples on a YSI 2300 STAT PLUS (Yellow Springs, OH). Glycosylated hemoglobin (HbA1c) concentrations were analyzed by Diabetes Technologies, Inc. (Thomasville, GA) using the HPLC-BA analytical method. Plasma was assayed in duplicate for insulin concentrations using a radioimmunossay (Diagnostics Products Corporation-DPC, Los Angeles, CA). The intra- and interassay coefficients of variation for the insulin assay were 7.6% and 8.9%, respectively. The whole-body insulin sensitivity index was determined as per Matsuda and DeFronzo’s calculation (21), with glucose concentrations presented as milligrams per deciliter (mg dL⁻¹) and insulin concentrations presented as microunits per liter (μU L⁻¹). Mean values are the average concentrations obtained at 0, 30, 60, 90, and 120 min during the oral glucose tolerance test. Lastly, glucose area under the curve was determined from the OGTT using GraphPad 5.0 (La Jolla, CA).

**Anthropometrics and VO₂peak.** BMI was calculated and percent body fat was determined via the Bod Pod (Life Measurements, Concord, CA). Waist circumference (cm) was measured at the level of the umbilicus. VO₂peak was determined by a walking treadmill protocol using indirect calorimetry (Quark b²; Cosmed, Rome, Italy) with a 12-lead ECG recorded at rest, during each stage of exercise, as well as into recovery (14).

**Statistical analysis.** HRV and the whole-body insulin sensitivity data were not normally distributed and were log-transformed to meet the assumption of normality when using parametric statistical analyses. Back-transformed whole-body insulin sensitivity index data are presented in Table 1. A two-way ANOVA with repeated measures (between subject—T2D and obese nondiabetic; within subject—before vs after training) was used to determine differences in VO₂peak, anthropometrics, glucose tolerance, and HRV within each HRV grouping (e.g., LCVM vs HCVM). An ANCOVA was conducted on differences in VO₂peak to control for any potential effect of

### Table 2. Type and classification of medication with number of participants listed by category.

<table>
<thead>
<tr>
<th>Category</th>
<th>T2D LCVM</th>
<th>T2D HCVM</th>
<th>Obese, Not Diabetic LCVM</th>
<th>Obese, Not Diabetic HCVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipid lowering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statin</td>
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<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Phenofibrate</td>
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<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ezetimibe</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Glucose lowering</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Metformin</td>
<td>9</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thiazolidinedione</td>
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<td>2</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Sulfonylides</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Antihypertensive</td>
<td></td>
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<td></td>
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<tr>
<td>ACE inhibitors</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ARBs</td>
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<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hydrochlorothiazides</td>
<td>0</td>
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<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Antidepressant</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
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<td>5</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

Subjects may be counted more than once if they were prescribed more than one medication.

ACE, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; CVM, cardiovascular modulation.
statin use. Correlations were conducted on the change in $\dot{V}O_2$ peak with changes in body weight, glucose area under the curve, and whole-body insulin sensitivity using Pearson correlation coefficients. Appropriate post hoc analyses were conducted if significant interactions were detected. Data are presented as means ± SD. Significance was set at $\alpha = 0.05$.

RESULTS

$\dot{V}O_2$ peak is presented in Figure 1. Both relative (A) and absolute (B) $\dot{V}O_2$ peak increased after the training period among individuals classified as having HCVM ($P < 0.05$), regardless of diabetes status. No change in $\dot{V}O_2$ peak was observed among those classified as having LCVM. $\dot{V}O_2$ peak expressed relative to lean body mass did not alter any of our findings. Furthermore, statin use did not influence our results based on the ANCOVA.

The pretraining $\dot{V}O_2$ peak appeared to be different between the subjects in the HCVM and LCVM groups (Fig. 1). This was further explored, and there was a medium effect size associated with this difference, although statistical significance was not achieved ($\eta^2 = 0.071$) (3).

Table 1 depicts anthropometric, glucose tolerance, and HRV data. No baseline differences were observed in body weight, BMI, and percent body fat. The T2D group had a larger waist circumference and higher glucose area under the curve at baseline ($P < 0.05$). Body weight, BMI, and waist circumference decreased among those classified as having HCVM after the training intervention ($P < 0.05$), with no training effect observed in those classified as having LCVM. Diabetic status did not affect these parameters. No effects were observed for percent body fat.

The glucose area under the curve decreased among individuals with T2D classified as having LCVM ($P < 0.05$), with no changes in the HCVM group (Table 1). The whole-body insulin sensitivity index increased with training in the LCVM group when considering T2D and obese nondiabetics together ($P < 0.05$), but for individuals with T2D only, those classified as having HCVM had increased insulin sensitivity index ($P < 0.05$) (Table 1).

By design, the HCVM groups were different from the LCVM groups ($P < 0.05$), with no effect of diabetes status. After the training period, HRV HF increased among those classified as having LCVM ($P < 0.05$), with no effect of diabetes status. No effect of training was observed for LF (Table 1).

Correlations. The change in $\dot{V}O_2$ peak (expressed as either relative or absolute) was not associated with the change in body weight among the HCVM group ($r = 0.20$ and $r = 0.27$, respectively), but the change in $\dot{V}O_2$ peak (relative) was associated with the change in body weight among the LCVM group ($r = 0.39$, $P < 0.05$). The change in $\dot{V}O_2$ peak was also not associated with whole-body insulin sensitivity (HCVM, $r = -0.07$; LCVM, $r = 0.11$) or glucose area under the curve (HCVM, $r = -0.02$; LCVM, $r = -0.15$).

DISCUSSION

The primary finding of this study is that, in sedentary obese subjects, with and without T2D, CVM before the beginning
of the training program appeared to affect the response to training. In particular, obese individuals with and without T2D who had HCVM before the commencement of an exercise program showed greater improvements in aerobic capacity compared to those with LCVM, as measured by HRV. In addition, aerobic exercise improved body weight in the HCVM group to a greater extent than the LCVM group, but this change could not explain the improvements in aerobic capacity. Yet, the LCVM group demonstrated a significant relationship between weight change and VO2peak (relative, not absolute), which may suggest that it is more important for this group to experience weight loss to achieve improvements in exercise tolerance, although aerobic capacity did not improve among the LCVM group overall. Further, statin use did not influence our findings, given recent evidence in humans that statins may negatively affect potential for increases in VO2peak (22). Thus, baseline autonomic function appears to be a significant contributor to beneficial exercise training–induced changes in obese individuals with and without T2D.

Changes in fitness may not explain changes in other cardiovascular risk factors. Gibbs et al. (6) explored data from the Look AHEAD study, a large multiyear lifestyle intervention trial, and found that changes in fitness and body weight explained a relatively small amount of variability (0.1%–9.3%) in the 1-yr change in traditional cardiovascular risk factors (e.g., fasting glucose, HbA1c, high-density cholesterol, triglycerides, diastolic blood pressure). Thus, the change in cardiovascular risk factors did not contribute to substantial changes in fitness and body weight, suggesting that additional parameters may explain changes in VO2peak. Hence, factors such as CVM may play an important role in determining the responsiveness to a training program. Our data suggest that baseline parasympathetic modulation is an important factor contributing to improvements in aerobic capacity after endurance training. It is possible that HCVM at baseline allows for such changes in aerobic capacity, regardless of diabetes status, because HCVM may be protective against cardiac autonomic neuropathy, or that HCVM is related to better cholinergic control of peripheral circulation. However, these hypotheses warrant further investigation.

Glucose control, insulin resistance, endothelial dysfunction, peripheral oxygen utilization, and central oxygen delivery have all been implicated in poor exercise capacity in T2D, as depicted in two reviews (26,29). Our study resulted in a small improvement in glucose control among the T2D group with LCVM (e.g., glucose area under the curve), yet the LCVM group did not increase VO2peak. Thus, our exercise training data support the lack of association between glucose control and cardiovascular fitness described in studies of acute exercise and glucose control (18,27,31). Insulin resistance has also been associated with reduced VO2peak in T2D (18,20,27,30,32). We observed no significant association between glucose area under the curve and whole-body insulin sensitivity and changes in VO2peak, suggesting that insulin sensitivity (or glucose tolerance) cannot explain the increase in VO2peak with exercise training. It is possible that the training intensity in our study was not high enough to induce significant changes in insulin sensitivity or possibly a more sensitive model for estimating insulin resistance (e.g., clamp models) would be needed detect such changes. Thus, these data support the importance of pretraining vagal modulation as an important contributor in improving VO2peak independent of changes in glucose tolerance or insulin sensitivity.

Recently, Notarius et al. (24) showed that aerobic capacity was associated with neurovascular coupling in middle-aged healthy men, as measured with muscle sympathetic nerve activity (a marker of sympathetic outflow), during lower body negative pressure. They reported a higher correlation among low-fit middle-aged men with sympathetic activity versus higher-fit men (24), suggesting fitness status and autonomic function are interconnected. Generally, individuals with LCVM are likely to have a larger sympathetic component driving autonomic responses regardless of diabetic status. Thus, the prevailing existing evidence suggests that low fitness is associated with low parasympathetic modulation and high sympathetic output. Our data extend these observations showing that low baseline parasympathetic modulation prevented endurance training–induced improvements in cardiovascular fitness. Furthermore, high levels of baseline parasympathetic modulation were required for fitness to improve, suggesting that autonomic status is an important contributor to fitness gains. In addition, it is important to note that our subjects with T2D exhibited good glucose control (7.2% HbA1c, no change with training) and also did not report peripheral neuropathy. Future studies are needed to investigate the response to endurance training in T2D across a glucose control continuum.

No baseline differences between individuals with or without T2D were found for either LF or HF. By design, group differences for HF were observed between HCVM and LCVM groups, whereas these differences were unaffected by diabetes status. A training effect on HF was observed for individuals classified as having LCVM, suggesting a level of plasticity in this marker of parasympathetic modulation. It is possible that a higher training stimulus (e.g., ~75% VO2peak or high-intensity interval training) may impart larger changes in HRV (25), which may be coupled (or not coupled) with larger improvements in VO2peak. The role of pretraining parasympathetic modulation on the responsiveness to a higher-intensity program still needs to be determined. It is possible that LF was unaffected because of the current belief that LF is composed of both sympathetic and parasympathetic influences and perhaps there was a cancellation effect. Interestingly, recent data suggest that LF may in fact be indicative of baroreceptor sensitivity; however, this needs to be explored further in this population (23). However, the improvement in HF in the LCVM group suggests that endurance training can change parasympathetic modulation in obese individuals. Thus, it is possible that a longer period of endurance training is needed to change VO2peak in individuals with LCVM because VO2peak may improve only after parasympathetic modulation is improved. Previous reports have established...
the effectiveness of the mode, duration, and intensity of individual exercise sessions on HRV in healthy young and older populations (10,25,35). Yet, the exact training-induced dose–response relationship in relation to autonomic function and aerobic capacity in obese individuals with and without T2D is unknown at this time. It is also possible that our data may be a reflection of a “regression toward the mean” artifact; however, ANCOVA does not statistically suggest that this is occurring in our data and we cannot fully rule it out either.

This study has several limitations. We did not measure leisure time physical activity, and this may have an important effect on peak aerobic capacity (8); however, all subjects were instructed to maintain their leisure time physical activity. The lack of a healthy nonobese control group may be an additional limitation; however, the main objective of this study was to determine the influences of CVM on exercise training responsiveness in individuals with T2D. Since obesity is a common feature of T2D, we chose to study obese individuals without T2D as our control. Finally, the exercise program consisted of mostly home-based exercise sessions; however, this was countered with regular laboratory-based supervised sessions to ensure adequate opportunity to adjust the training load.

In conclusion, this study demonstrates that obese individuals, with or without T2D, when classified as having HCVM before exercise training, have a greater propensity to improve VO2peak after a 16-wk aerobic training program. While the improvements in VO2peak, body weight, BMI, and waist circumference are modest among the HCVM group, this study corroborates previous research (11,12,16), suggesting that the individual’s response to a training stimulus should be individualized for maximum benefit.

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REFERENCES


