Time Course Changes in Confirmed ‘True’ VO₂ max After Individualized and Standardized Training

Authors
Ryan Weatherwax¹, ², Nigel Harris¹, Andrew E. Kilding¹, Lance Dalleck¹, ²

Affiliations
1 Human Potential Centre, Auckland University of Technology, Auckland, New Zealand
2 Recreation, Exercise and Sport Science, Western State Colorado University, Gunnison, United States
3 Sports Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand

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ABSTRACT
This study sought to examine time course changes in maximal oxygen consumption (VO₂ max) confirmed with verification testing following 12 weeks of standardized vs. individualized exercise training. Participants (N = 39) were randomly allocated to differing exercise intensity prescription groups: ventilatory threshold (individualized) or % heart rate reserve (standardized). At baseline, 4, 8, and 12 weeks, participants completed maximal exercise testing with a verification protocol to confirm ‘true VO₂ max.’ VO₂ max in the standardized group changed from 24.3 ± 4.6 ml · kg⁻¹ · min⁻¹ at baseline to 24.7 ± 4.6, 25.9 ± 4.7, and 26.0 ± 4.2 ml · kg⁻¹ · min⁻¹ at week 4, 8, and 12, respectively, with a significant difference (p < 0.05) in VO₂ max at week 8 and 12 compared to baseline. The individualized group had increases in VO₂ max from 29.5 ± 7.5 ml · kg⁻¹ · min⁻¹ at baseline to 30.6 ± 8.4, 31.4 ± 8.4, and 32.8 ± 8.6 ml · kg⁻¹ · min⁻¹ at week 4, 8, and 12, respectively. In the individualized group, there were significant differences (p < 0.05) in VO₂ max from baseline to week 8 and 12 and a significant increase in VO₂ max from week 8 to 1 online 2. Although not statistically significant, our preliminary data demonstrates a more rapid and potent improvement in VO₂ max when exercise intensity is individualized. This is the first investigation to employ use of the verification procedure to confirm ‘true VO₂ max’ changes following exercise training using ventilatory thresholds.

Introduction
Low cardiorespiratory fitness (CRF) is a well-established predictor of cardiovascular disease and mortality [5, 13, 40]. It has generally been accepted that CRF can be improved following a regular aerobic exercise training program [15]. Furthermore, with the emerging concept of ‘Exercise is Medicine’ and using individualized exercise as medicine [7], the time course changes in CRF and, specifically, maximal oxygen uptake (VO₂ max) need to be better understood to properly determine exercise doses (i.e., intensity, volume). An understanding of the time course changes in CRF is imperative to properly prescribe and adjust training regimens to enhance adaptations [7].

Much of the literature on time course changes investigates a standardized methodology of exercise prescription using heart rate reserve (HRR) [37], percent peak oxygen consumption (VO₂ peak) [33], and percent VO₂ max [28]. Recently, there has been evidence to show that individualized exercise prescription can also be effective. However, little is known about the time course changes following exercise training using ventilation thresholds.
that a more individualized exercise prescription using metabolic threshold (i.e., ventilatory thresholds) enhances training adaptations and overall responsiveness to VO\textsubscript{2max} [11, 45]. Therefore, it is important to understand the differences in time course outcomes following a standardized compared to an individualized exercise prescription. To the best of our knowledge, this has yet to be reported in the literature.

Our knowledge on interindividual differences and time course changes has been confounded based on methodological weaknesses of accepted primary and secondary criteria used to determine VO\textsubscript{2max} [6, 31, 32, 38]. There is often a discrepancy in how maximal values are reported and it has become common that the highest achieved VO\textsubscript{2} (VO\textsubscript{2peak}) during a maximal test is used to prescribe intensity and evaluate effectiveness of a training intervention, but a peak value may not directly represent a true maximal value of aerobic capacity. For example, Ross and colleagues [33] reported VO\textsubscript{2peak} at 4, 8, 16, and 24 weeks to identify the effects of intensity on interindividual responses to CRF. However, since only peak values were reported, we cannot conclusively determine that CRF was maintained, declined, or improved because a true maximal value is not reported. The use of a supramaximal test following a graded exercise test (GXT) was first reported by Niemala and colleagues [30] and has since evolved into what is commonly considered a ‘verification protocol’ to confirm a ‘true VO\textsubscript{2max}’ [12, 19, 26, 27, 34]. Indeed, the efficacy of a verification protocol has been confirmed in sedentary men and women [2], middle-aged and older adults [10], sedentary adults with obesity [35], and altitude-residing endurance runners [43]. However, to our knowledge, a verification protocol to confirm VO\textsubscript{2max} has not been used to examine time course changes due to steady-state CRF training with exercise intensity determined by ventilatory threshold measurements.

The main purpose of the current investigation was to examine the effects of standardized and individualized exercise prescription on VO\textsubscript{2max} confirmed by a verification bout at 4-week increments over a 12-week CRF training intervention. It was hypothesized that an individualized method of exercise intensity prescription would provide a more rapid and potent increase in VO\textsubscript{2max} compared to a standardized technique.

Materials and Methods

The current investigation involved repeated measurements (every fourth week) to understand the differences in time course changes of VO\textsubscript{2max} with individualized and standardized exercise prescription. A detailed description of the study and participant flow diagram has been previously published [44]. This study was carried out in accordance with and approved by the Auckland University of Technology Ethics Committee (16/264) and the Western State Colorado University Institutional Review Board (HRC2016–01–90R6) and meets the ethical standards of this journal [17]. All participants provided written informed consent in accordance with the Declaration of Helsinki.

Participants

Sedentary men and women were recruited from a local community-based wellness program and the general community via advertisement at the university, local newspaper, and word of mouth. Participants were eligible for inclusion if they were between the ages of 30 and 75, considered low to moderate risk based on the American College of Sports Medicine Standards [1], and participated in less than 30 min of moderate intensity physical activity on 3 days a week or less for the last 3 months. Participants were excluded from the investigation if they reported signs or symptoms suggestive of pulmonary, cardiovascular, or metabolic conditions determined from a standard medical history questionnaire.

Experimental testing

Outcome variables, other than a dietary recall and physical activity questionnaire, were obtained at baseline, week 4, week 8, and week 12 following the completion of the exercise intervention. To the best of our ability, we maintained consistency with day of the week and time of day between repeated testing sessions for each participant with repeated testing occurring within a day and ± 3 h of the original day of the week and time of day. All participants were instructed to refrain from any strenuous exertion for the 12 h prior to testing.

Resting and anthropometric measurements

Resting heart rate (RHR) was analyzed following standardized procedures [1]. In summary, when participants arrived at the laboratory, they sat for 5 min with sufficient back support, feet on the ground, and arms supported near heart level. Following the 5 min of seated rest, a medical-grade pulse oximeter (Nonin Medical Inc., Plymouth, MN, USA) was used to establish resting heart rate.

Participants were weighed to the nearest 0.1 kg and height measured to the nearest 0.5 cm on a calibrated, medical-grade scale and a stadiometer (Tanita Corporation WB-3000, Tokyo, Japan), respectively.

Dietary analysis

Throughout the 12-week intervention, participants were asked to maintain their regular nutritional habits. At baseline and post-intervention, a 3-day dietary intake recall including two weekdays and one weekend day with the inclusion of types of food/drink, portion sizes, and any specific nutritional information they could provide was solicited. The dietary recall was used to investigate energy intake and the proportion of kilocalories from carbohydrates, protein, and fat.

Maximal exercise testing with verification protocol

Participants completed a GXT using a modified-Balke, pseudoramp protocol on a motorized treadmill (Powerjog GX200, Maine, USA). Following a 4-min warm-up with an increasing workload, participants walked or jogged at a self-selected pace with a starting incline of 0 % and had a subsequent increase in incline of 1 % every min until volitional fatigue was reached. Throughout the GXT, participant HR using a chest strap and radio-telemetric receiver (Polar Electro, Woodbury, NY, USA) and expired air and gas exchange data using a metabolic analyzer (Parvo Medics TrueOne 2.0, Salt Lake City, UT, USA) were continuously monitored and recorded. Prior to each exercise test, the metabolic analyzer was calibrated per manufacturer guidelines in the instructional manual with a calibration gas mixture (16.00 % O\textsubscript{2} and 4.00 % CO\textsubscript{2}) and room air (20.93 % O\textsubscript{2} and 0.003 % CO\textsubscript{2}). Gas exchange data were averaged for every
15 sec, and VO2max was determined by averaging the final two 15sec VO2 average data during the GXT. The highest achieved HR during the GXT was considered the maximal HR (HRmax).

In order to confirm ‘true VO2max,’ a verification protocol was performed 20 min following the completion of the GXT. The verification protocol included a 4-min warm-up followed by a volitional test to exhaustion at a constant workload that was set at 5% higher than the last completed stage of the GXT. The workload was determined by taking the final metabolic equivalent (MET) value for the GXT and increasing the speed, incline, or combination of the two to achieve a 5% higher MET value for the verification bout. Gas exchange data and HR were continuously monitored and averaged every 15 sec. VO2max during the verification protocol was established in the same manner as the GXT, with the average of the final two 15sec data points for VO2. A ‘true VO2max’ was confirmed if the GXT and verification protocol were within ±3.0%, based on previously published methods [10, 43]. If there was a greater than ±3.0% between the GXT and verification bout, participants repeated the maximal exercise testing with verification protocol within 24–72 h until ‘true VO2max’ was confirmed with the ±3.0% criterion.

**Determination of ventilatory thresholds**

The first ventilatory threshold (VT1) and the second ventilatory threshold (VT2) were determined based on previously published methods [16, 39]. In summary, ventilatory thresholds were determined based on visual inspection of time plotted against the ventilatory equivalents of oxygen (VE/VO2) and the ventilatory equivalents of carbon dioxide (VE/VCO2). VT1 was determined to occur when VE/VO2 increased without a concurrent increase in VE/VCO2 and VT2 occurred at the point in which both VE/VO2 and VE/VCO2 increased simultaneously. All assessments of VT1 and VT2 were completed by two experienced exercise physiologists. If there were conflicting results, the original assessments were reevaluated, and a consensus was agreed upon.

**Exercise prescription**

Following recruitment and prior to baseline testing, participants were randomized into one of two exercise training groups according to a computer-generated sequence of random numbers that was stratified by sex. Participants exercised on 3 days a week throughout the 12-week study with an incremental increase in HR and duration. Exercise prescription was based on individualized or standardized methods using ventilatory threshold measurements or heart rate reserve (HRR), respectively. Because exercise testing occurred every 4 weeks, values were updated based on the most current exercise testing session. The week-to-week exercise prescription for both groups has been previously published in detail [44]. In summary, the standardized group started with an exercise intensity between 40–45% of HRR and progressed to 60–65% of HRR. The individualized group used the following criteria to establish training intensity:

- Target HR < VT1 = HR range of 10 bpm below VT1 to the HR at VT1
- Target HR ≥ VT1 to < VT2 = HR range of 15 bpm directly between VT1 and VT2
- Target HR ≥ VT2 = HR range of 10 bpm above VT2

Exercise volume was prescribed based on energy expenditure per kg of body weight a week (kcal·kg⁻¹·wk⁻¹) rather than a standard time per exercise session to establish an isocaloric exercise volume across individuals and groups. The total weekly energy expenditure was then divided by 3 to get the daily exercise energy expenditures. The developed energy expenditures were then correlated to the exercise testing gas exchange values to determine a specific duration (i.e., time in min) for each exercise session. A detailed description of the development of energy expenditure criteria has been previously published [44].

**Exercise training**

Upon arrival to the lab, participants rested for 5 min in a seated position, and resting HR was recorded subsequently. After completion of resting measurements, participants warmed up at a self-selected pace with increases in workload for 5 min until the prescribed exercise intensity was reached. Participants then exercised for their prescribed duration based on the calculated energy expenditure, and HR was continuously monitored using a chest strap and radiotelemetric receiver (Polar Electro, Woodbury, NY, USA). At approximately 1/3 and 2/3 the total time, a research assistant ensured the participant was within the correct HR range. Following the designated time, participants completed a 5 min cool-down with decreasing workloads until HR was within 15 bpm of resting values.

**Statistical analysis**

All statistical analyses were performed using SPSS Version 22.0 (Chicago, IL, USA). Data were reported as mean ± standard deviation (SD). Based on a power calculation previously published [44] and an assumption of a 20% dropout rate, 20 participants were desired for each group. Baseline group differences were determined based on an independent-samples t-test with p < 0.05. All measures were analyzed by a general linear model two-way ANOVA for repeated measures (baseline, wk 4, wk 8, and wk 12) with intensity as the between-subject variable. When appropriate, a subsequent post hoc comparison using a Bonferroni correction was completed. A one-way ANOVA was used to understand the changes in time point and VO2max. The assumption of normality was tested by examining normal plots of the residuals in ANOVA models and regarded as normally distributed if Shapiro-Wilk tests were not significant [9]. Effect sizes were calculated using means and pooled SD. The probability of making a type I error was set at p ≤ 0.05 for all statistical analyses. In order to be included in the data analysis, participants needed an adherence level ≥ 70% with strict adherence to the targeted day-to-day exercise intensity and duration.

**Results**

**Participants**

A total of 49 participants were recruited and 39 participants completed all testing sessions with an adherence rate of 82.9 ± 5.7% and 86.1 ± 4.7% for the standardized and individualized groups, respectively. The 10 participants not included in the final data were excluded due to unrelated medical issues (1 and 2 participants in the standardized and individualized group, respectively), self-withdrawal from the study (3 participants in the standardized group),
or did not achieve ≥ 70% adherence (1 and 3 participants in the standardized and individualized group, respectively). Baseline and every fourth week physical and physiological characteristics are shown in ▶ Table 1. There was no statistical significance between pre- and post-intervention dietary intake as shown in ▶ Table 2.

Intervention fidelity for both groups in terms of intensity and exercise duration was very high, as shown in ▶ Table 3. In only a single instance (standardized week 3), the actual mean min completed was 3 min less than the target range for that week.

**Time course changes**

There was an overall change in VO2max from baseline to week 12 of 1.7 ± 1.9 ml · kg⁻¹ · min⁻¹ and 3.4 ± 1.5 ml · kg⁻¹ · min⁻¹ for the standardized and individualized groups, respectively. A two-way repeated measures ANOVA revealed a main effect for group (F = 7.866; p < 0.05; partial eta squared = 0.175). There was a significant interaction between group and time point (F = 3.555; p < 0.05; partial eta squared = 0.316) and individualized group (F = 29.559; p < 0.05; partial eta squared = 0.622). Post hoc analysis revealed that VO2max was significantly increased during week 8 and 12 compared to baseline for both groups and differed significantly from week 8 to week 12 for the individualized group (▶ Fig. 1).

**GXT and verification testing**

Only 4 participants (2 participants at baseline and 2 participants at week 4) had greater than a ± 3.0% difference between the GXT and verification bout, but 3 of these tests were rescheduled, and subsequently the verification protocol was confirmed. On one occasion during week-4 testing, one participant had a 4.0% difference between GXT and verification, and a subsequent testing session to confirm VO2max was not completed. However, VO2max was confirmed for all of the other testing sessions. The individual differences and group means for VO2max in the GXT and verification bout can be seen in ▶ Fig. 2, and the speed, incline, and duration for the GXT and verification protocol are highlighted in ▶ Table 4.

**Table 1** Physical and physiological characteristics at baseline, week 4, week 8, and 12 weeks for standardized and individualized groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standardized (n = 20; women = 16, men = 4)</th>
<th>Individualized (n = 19; women = 14, men = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>51.2 ± 12.5</td>
<td>51.7 ± 12.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163.8 ± 9.5</td>
<td>163.8 ± 9.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.9 ± 20.7</td>
<td>83.9 ± 20.7</td>
</tr>
<tr>
<td>BMI</td>
<td>29.5 ± 5.5</td>
<td>29.5 ± 5.5</td>
</tr>
<tr>
<td>Resting HR (b · min⁻¹)</td>
<td>70.0 ± 8.8</td>
<td>68.8 ± 9.7</td>
</tr>
<tr>
<td>Maximal HR (b · min⁻¹)</td>
<td>165.2 ± 16.1</td>
<td>166.3 ± 16.3</td>
</tr>
<tr>
<td>VO2max (L · min⁻¹)</td>
<td>2.0 ± 0.6</td>
<td>2.2 ± 0.6</td>
</tr>
<tr>
<td>% Diff in VO2max (GXT and Verification)</td>
<td>-0.2 ± 1.8</td>
<td>-0.4 ± 1.8</td>
</tr>
<tr>
<td>% Δ in Absolute VO2max</td>
<td>2.0 ± 6.7</td>
<td>6.9 ± 8.4</td>
</tr>
</tbody>
</table>

Values are mean ± SD. BMI, basal metabolic rate; GXT, graded exercise test; HR, heart rate; Δ, change; VO2max, maximal oxygen uptake; †Significantly different from previous time point; ‡Significantly different from baseline.

**Discussion**

This study sought to compare the VO2max time course changes at 4-week increments between a standardized and individualized 12-week CRF training program with exercise intensity established based on %HRR or ventilatory thresholds. The main finding from the present study was that our preliminary data, although not statistically significant, demonstrates that an individualized approach to method of exercise intensity prescription elicits more rapid and potent improvement in VO2max relative to a standardized paradigm. Indeed, at week 4, there was nearly a two-fold greater improvement for the individualized group compared to the standardized group. Furthermore, even though both training approaches elicited a statistically significant improvement in VO2max at week 12 compared to baseline, there was a 41% higher improvement in the individualized group compared to the standardized group based on mean percent changes. Moreover, these changes in CRF are due to ‘true’ adaptation based on the use of a verification bout to confirm that VO2max was achieved and results were not reported as simply peak values. Overall, these novel findings add to the growing body of evidence [7, 11, 45] that an individualized exercise prescription for steady-state aerobic exercise enhances training adaptations.

Our findings that VO2max increased 1.7 ± 1.9 ml · kg⁻¹ · min⁻¹ and 3.4 ± 1.5 ml · kg⁻¹ · min⁻¹ for the standardized and individualized groups, respectively, following the 12-week intervention were consistent with previous findings using similar exercise prescription protocols for 12 weeks [45] and 13 weeks [11]. However, results from this study are the first to demonstrate the difference in time course changes between a standardized and individualized exercise prescription. Based on our findings, it was shown that after 8 weeks there is a statistically significant improvement in VO2max compared to baseline. These results are consistent with previous findings [14, 33]. Following the first 9 weeks of training at either a high (80–85% VO2max) or low intensity (45% VO2max) during an 18-week training intervention, 74 and 90% of the overall changes were demonstrated in the high and low intensity, respectively [14]. When comparing these results with those seen in the current 12-week training intervention, there are differences in the rate and magnitude of the improvements, with the current study showing a more rapid and potent increase in VO2max compared to the previous studies.
intervention, 90% of the overall change in VO$_2$max was seen by week 8 for the standardized group. However, for the individualized group, only 55% of the overall change in VO$_2$max at week 8 was seen. This is lower than previously reported for the same time point (i.e., week 8) and indicating there was a greater magnitude of change from week 8 to 12 in the current investigation compared to week 8 to 18 previously [14]. This is also noteworthy because the change in VO$_2$max between week 8 and 12 for the individualized intervention, 90% of the overall change in VO$_2$max was seen by the change in VO$_2$max between week 8 and 12 for the individualized group was the only time in which there was a statistically significant change compared to the preceding time points.

To our knowledge, the current study was the first to use a verification protocol to confirm VO$_2$max when investigating time course changes when comparing exercise intensity prescription

### Table 2 Alterations in dietary intake in response to 12 weeks of standardized or individualized CRF training in sedentary adults.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Week 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calorie intake (kcal)</td>
<td>1520.3 ± 563.2</td>
<td>1518 ± 500.8</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>160.4 ± 60.5</td>
<td>158.8 ± 63.9</td>
</tr>
<tr>
<td>Lipid (g)</td>
<td>61.1 ± 31.2</td>
<td>62.8 ± 26.4</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>64.1 ± 16.4</td>
<td>63.8 ± 22.0</td>
</tr>
<tr>
<td>Carbohydrate (%)</td>
<td>41.7 ± 6.9</td>
<td>40.9 ± 7.8</td>
</tr>
<tr>
<td>Lipid (%)</td>
<td>35.9 ± 9.2</td>
<td>37.1 ± 8.4</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>18.2 ± 6.3</td>
<td>17.8 ± 5.1</td>
</tr>
</tbody>
</table>

Values are mean ± SD

### Table 3 Exercise prescription and progression for standardized and individualized exercise prescription based on percentage of heart rate reserve and ventilatory thresholds, respectively.

<table>
<thead>
<tr>
<th>Week</th>
<th>Target HR</th>
<th>Actual HR</th>
<th>Target Min</th>
<th>Actual Min</th>
<th>Target HR</th>
<th>Actual HR</th>
<th>Target Min</th>
<th>Actual Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>108 ± 10</td>
<td>113 ± 12</td>
<td>27 ± 6 to 32 ± 9</td>
<td>32 ± 9</td>
<td>105 ± 14 to 115 ± 14</td>
<td>114 ± 14</td>
<td>26 ± 6 to 31 ± 9</td>
<td>31 ± 8</td>
</tr>
<tr>
<td>2</td>
<td>108 ± 10</td>
<td>113 ± 11</td>
<td>41 ± 10 to 48 ± 13</td>
<td>46 ± 11</td>
<td>105 ± 14 to 115 ± 14</td>
<td>114 ± 14</td>
<td>39 ± 10 to 47 ± 14</td>
<td>44 ± 9</td>
</tr>
<tr>
<td>3</td>
<td>108 ± 10</td>
<td>113 ± 11</td>
<td>54 ± 13 to 64 ± 17</td>
<td>51 ± 10</td>
<td>105 ± 14 to 115 ± 14</td>
<td>114 ± 13</td>
<td>52 ± 13 to 63 ± 18</td>
<td>54 ± 9</td>
</tr>
<tr>
<td>4</td>
<td>118 ± 11</td>
<td>123 ± 11</td>
<td>45 ± 8 to 49 ± 8</td>
<td>47 ± 8</td>
<td>122 ± 15 to 136 ± 15</td>
<td>131 ± 15</td>
<td>38 ± 8 to 48 ± 13</td>
<td>42 ± 9</td>
</tr>
<tr>
<td>5</td>
<td>124 ± 11</td>
<td>128 ± 11</td>
<td>42 ± 8 to 47 ± 8</td>
<td>45 ± 7</td>
<td>122 ± 15 to 136 ± 15</td>
<td>134 ± 17</td>
<td>38 ± 8 to 48 ± 13</td>
<td>43 ± 9</td>
</tr>
<tr>
<td>6</td>
<td>124 ± 11</td>
<td>128 ± 11</td>
<td>42 ± 8 to 47 ± 8</td>
<td>45 ± 7</td>
<td>122 ± 15 to 136 ± 15</td>
<td>135 ± 16</td>
<td>38 ± 8 to 48 ± 13</td>
<td>44 ± 9</td>
</tr>
<tr>
<td>7</td>
<td>124 ± 11</td>
<td>128 ± 11</td>
<td>48 ± 9 to 53 ± 9</td>
<td>49 ± 7</td>
<td>122 ± 15 to 136 ± 15</td>
<td>132 ± 16</td>
<td>41 ± 8 to 52 ± 11</td>
<td>49 ± 9</td>
</tr>
<tr>
<td>8</td>
<td>124 ± 11</td>
<td>128 ± 11</td>
<td>52 ± 8 to 58 ± 10</td>
<td>53 ± 8</td>
<td>125 ± 14 to 139 ± 15</td>
<td>134 ± 16</td>
<td>45 ± 8 to 57 ± 11</td>
<td>50 ± 9</td>
</tr>
<tr>
<td>9</td>
<td>129 ± 11</td>
<td>134 ± 12</td>
<td>48 ± 9 to 53 ± 9</td>
<td>51 ± 8</td>
<td>144 ± 15 to 154 ± 15</td>
<td>149 ± 17</td>
<td>37 ± 9 to 42 ± 10</td>
<td>40 ± 10</td>
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<td>10</td>
<td>129 ± 11</td>
<td>134 ± 12</td>
<td>48 ± 8 to 53 ± 9</td>
<td>50 ± 7</td>
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<td>148 ± 17</td>
<td>37 ± 9 to 42 ± 10</td>
<td>40 ± 10</td>
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<tr>
<td>11</td>
<td>129 ± 11</td>
<td>134 ± 12</td>
<td>53 ± 8 to 59 ± 9</td>
<td>53 ± 6</td>
<td>144 ± 15 to 154 ± 15</td>
<td>148 ± 17</td>
<td>41 ± 10 to 47 ± 11</td>
<td>44 ± 10</td>
</tr>
<tr>
<td>12</td>
<td>129 ± 11</td>
<td>134 ± 12</td>
<td>53 ± 8 to 59 ± 9</td>
<td>53 ± 6</td>
<td>144 ± 15 to 154 ± 15</td>
<td>147 ± 17</td>
<td>41 ± 10 to 47 ± 11</td>
<td>45 ± 10</td>
</tr>
</tbody>
</table>

Values are mean ± SD. HR, heart rate; VT1, first ventilatory threshold; VT2, second ventilatory threshold; Mean ± SD HR values represent the average of all three training days within each week with averages calculated based on the recorded measurements obtained at 1/3 and 2/3 time points during each exercise session.
the use of an isocaloric dose of steady-state aerobic exercise using
HRR or threshold measures can increase VO$_2$max following 12
weeks of CRF training. However, it should be noted that the indi-
vidualized training group using ventilatory thresholds provided
more rapid and greater change in VO$_2$max. Such training might
therefore underpin its potential relatively greater efficacy for pre-
scription purposes by taking into account individual metabolic
characteristics that are not considered when using relative percent
methods. Therefore, it is recommended that steady-state aerobic
exercise prescription for sedentary individuals should be complet-
based on threshold measurements to take into consideration
individual metabolic characteristics and enhance training adapta-
tions. Furthermore, based on our data, if aerobic training adapta-
tions are not observed after 8 weeks of steady-state aerobic train-
ing, modifying the exercise prescription intensity or method of in-
tensity prescription (i.e., changing from a relative percent method
to an individualized method) should be considered to achieve the
desired results.

Limitations
A potential risk for selection bias exists in the present study because
the principal investigator was aware to which treatment group par-
ticipants were allocated and also performed all GXT and verifica-
tion protocol testing. However, the application of the verification
protocol likely minimized any potential selection bias due to its ro-
bustness for verifying ‘true VO$_2$max.’ Even though the participants
included in the study represent a standard exercise clinic demo-
graphic, there was a large age range and therefore the study group
not homogenous. There may be heterogeneity in results due to
age alone. Furthermore, men were underrepresented, accounting
for only 23% of the participants. At baseline, there was a significant
difference in VO$_2$max values with the individualized group having
higher values. However, although not statistically significant, based
on the results of the study the individualized group improved great-
er than the standardized group when, in theory, they had a lower
capacity to improve. Lastly, the issue of training responsiveness is
a nuanced area of study with multiple outcomes to assess, but the
current investigation identified only CRF (i.e., VO$_2$max) changes.
Future studies should take into consideration these limitations to
further address the time course changes in these exercise intensi-
ity prescription methods. Similarly, further research is warranted
to investigate a more comprehensive approach to understanding time
course changes with the development of a composite score to ex-

![Fig. 1] Group relative VO$_2$max at baseline, week 4, week 8, and
week 12 for standardized and individualized exercise prescription.
*Significantly different from previous time point; †significantly dif-
ferent from baseline.

![Fig. 2] Comparison of mean GXT trial VO$_2$max and verification trial VO$_2$max and individual (39 participants) VO$_2$max data represented by the line
graphs at baseline a, week 4 b, week 8 c, and week 12 d.
explore all training responsiveness factors (i.e., aerobic and cardiometabolic measurements).

**Conclusion**

In conclusion, an individualized exercise prescription based on metabolic characteristics elicits a more rapid and effective improvement in CRF. On a practical level and based on our data, exercise specialists may consider a reevaluation of the CRF training program for previously sedentary individuals if improvements in VO\(_{2}\)max are not observed after 8 weeks of training. Lastly, for the first time, we have demonstrated that the verification procedure can be successfully employed to confirm ‘true’ changes in VO\(_{2}\)max following exercise training comparing exercise intensity prescription differences using HRR and ventilatory threshold methods.

**Conflict of Interest**

Authors declare that they have no conflict of interest.

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