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Time Course Changes in Confirmed 'True' VO_2max After Individualized and Standardized Training

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ABSTRACT

This study sought to examine time course changes in maximal oxygen consumption (VO_2max) 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 VO_2max.' VO_2max in the standardized group changed from $24.3 \pm 4.6\,ml \cdot kg^{-1} \cdot min^{-1}$ at baseline to 24.7 ± 4.6, 25.9 ± 4.7, and $26.0 \pm 4.2\,ml \cdot kg^{-1} \cdot min^{-1}$ at week 4, 8, and 12, respectively, with a significant difference ($p < 0.05$) in VO_2max at week 8 and 12 compared to baseline. The individualized group had increases in VO_2max from online 2 $9.5 \pm 7.5\,ml \cdot kg^{-1} \cdot min^{-1}$ at baseline to 30.6 ± 8.4, 31.4 ± 8.4, and $32.8 \pm 8.6\,ml \cdot kg^{-1} \cdot min^{-1}$ at week 4, 8, and 12, respectively. In the individualized group, there were significant differences ($p < 0.05$) in VO_2max from baseline to week 8 and 12 and a significant increase in VO_2max from week 8 to 1 online 2. Although not statistically significant, our preliminary data demonstrates a more rapid and potent improvement in VO_2max when exercise intensity is individualized. This is the first investigation to employ use of the verification procedure to confirm 'true VO_2max' 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 (VO_2max) 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 (VO_2peak) [33], and percent VO_2max [28]. Recently, there has been evidence

that a more individualized exercise prescription using metabolic threshold (i. e., ventilatory thresholds) enhances training adaptations and overall responsiveness to VO_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_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_2 (VO_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_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_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_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_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_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_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, pseudo-ramp 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_2 and 4.00 % CO_2) and room air (20.93 % O_2 and 0.003 % CO_2). Gas exchange data were averaged for every

15 sec, and VO_2max was determined by averaging the final two 15-sec VO_2 average data during the GXT. The highest achieved HR during the GXT was considered the maximal HR (HR_{max}).

In order to confirm 'true VO_2max,' 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. VO_2max during the verification protocol was established in the same manner as the GXT, with the average of the final two 15-sec data points for VO_2. A 'true VO_2max' 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 VO_2max' 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/VO_2) and the ventilatory equivalents of carbon dioxide (VE/VCO_2). VT1 was determined to occur when VE/VO_2 increased without a concurrent increase in VE/VCO_2 and VT2 occurred at the point in which both VE/VO_2 and $VEVCO_2$ 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 ($kcal \cdot kg^{-1} \cdot wk^{-1}$) 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, participates 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 $p \leq 0.05$. 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 VO_2max. 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 $p \leq 0.05$ 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 show 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 were 3 min less than the target range for that week.

Time course changes

There was an overall change in VO_2max 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 = 0.88). The one-way ANOVA showed a main effect for time point on VO_2max for the standardized group ($F = 8.758$; $p < 0.05$; partial eta squared = 0.316) and individualized group ($F = 29.559$; $p < 0.05$; partial eta squared = 0.622). Post hoc analysis revealed that VO_2max 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 VO_2max was not completed. However, VO_2max was confirmed for all of the other testing sessions. The individual differences and group means for VO_2max 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**.

Discussion

This study sought to compare the VO_2max 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 VO_2max 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 VO_2max 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 VO_2max 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 VO_2max 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 VO_2max 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 % VO_2max) or low intensity (45 % VO_2max) 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

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

Parameter	Standardized (n = 20; women = 16, men = 4)				Individualized (n = 19; women = 14, men = 5)			
	Baseline	Week 4	Week 8	Week 12	Baseline	Week 4	Week 8	Week 12
Age (yr)	51.2 ± 12.5	-	-	-	44.9 ± 11.4	-	-	-
Height (cm)	168.3 ± 9.5	-	-	-	172.1 ± 7.1	-	-	-
Weight (kg)	83.9 ± 20.7	84.0 ± 20.3	83.9 ± 20.4	83.8 ± 20.3	80.6 ± 16.2	80.7 ± 15.8	80.2 ± 15.2	79.9 ± 15.2
BMI	29.5 ± 5.5	29.5 ± 5.3	29.5 ± 5.4	29.4 ± 5.3	27.1 ± 4.2	26.9 ± 4.0	26.9 ± 3.8	26.8 ± 3.8
Resting HR (b · min^{-1})	70.0 ± 8.8	69.9 ± 11.2	68.1 ± 8.4	68.2 ± 8.0	68.8 ± 9.7	72.4 ± 8.7	69.3 ± 9.4	68.1 ± 11.4
Maximal HR (b · min^{-1})	165.2 ± 16.1	164.5 ± 16.2	166.3 ± 16.3	164.9 ± 15.1	170.1 ± 18.4	171.7 ± 16.5	170.7 ± 14.7	169.2 ± 14.4
VO_2max (L · min^{-1})	2.0 ± 0.6	2.1 ± 0.6	2.2 ± 0.6†‡	2.2 ± 0.6‡	2.4 ± 0.8	2.5 ± 0.8	2.5 ± 0.8‡	2.6 ± 0.8†‡
% Diff in VO_2max (GXT and Verification)	−0.2 ± 1.8	0.0 ± 1.9	0.6 ± 1.7	−0.4 ± 1.8	0.2 ± 1.7	0.6 ± 2.1	0.7 ± 1.8	−0.7 ± 1.7
% Δ in Absolute VO_2max	-	2.0 ± 6.7	6.9 ± 8.4	7.5 ± 7.7	-	3.9 ± 8.0	6.1 ± 6.5	10.6 ± 5.3

Values are mean ± SD. BMI, basal metabolic rate; GXT, graded exercise test; HR, heart rate; Δ, change; VO_2max, maximal oxygen uptake; †Significantly different from previous time point; ‡significantly different from baseline

intervention, 90 % of the overall change in VO_2max was seen by week 8 for the standardized group. However, for the individualized group, only 55 % of the overall change in VO_2max 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_2max 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_2max when investigating time course changes when comparing exercise intensity prescription using HRR or ventilatory thresholds. Ensuring that a maximal aerobic value is achieved when investigating any changes due to modifying or differing exercise doses is imperative to understand true changes occurring from the intervention and not owing to how aerobic capacity is measured. Historically, a plateau in VO_2max (i. e., ≤ 150 ml · min^{-1}) at the ending stages of a GXT has been the primary criterion to determine 'true VO_2max' [41]. However, there has been inconsistency regarding the value for a plateau with the use of ≤ 150 ml · min^{-1} to ≤ 50 ml · min^{-1} [38], and there has been an incidence in plateau ranging from 0 % [34] to 100 % [3]. Therefore, the use of secondary criteria was proposed [20], but has since been highly criticized [6, 31]. Based on these considerations, VO_2peak rather than VO_2max has been recorded as a common aerobic outcome measure, especially when reporting functional capacity and fitness changes, and is used to prescribe exercise interventions [8, 18, 21, 33]. Unfortunately, VO_2peak does not directly indicate that aerobic adaptations have occurred due to the lack of sensitivity of this measurement [31]. Recently, although there is still debate on the overall topic [29], the use of a verification protocol to confirm VO_2max has been identified as a practical and sensitive measure to ensure that a 'true' maximal aerobic value has been achieved [38]. Furthermore, participants tend to exhibit greater maximal effort following a training intervention due to expecting improvements [25]. Indeed, it could be noted that a change in VO_2peak could be due to a greater increase in effort if there is minimal consideration to the testing methodology. With the use of a verification protocol, this overestimation of training adaptations is mitigated by ensuring all measurements are a 'true VO_2max' and representative of training adaptations [10, 31].

The relative percent method (i. e., using percentages of HR_{max}, HRR, VO_2max, and VO_2 reserve [VO_2R]) has been a common practice for prescribing exercise intensity. However, these values may not be sensitive enough to provide a workload that elicits the desired metabolic response [22, 42]. For example, a workload of 75 % VO_2max ranged between 86–118 % of the individual lactate thresh-

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

Parameter	Baseline	Week 12
Standardized		
Calorie intake (kcal)	1520.3 ± 563.2	1518 ± 500.8
Carbohydrate (g)	160.4 ± 60.5	158.8 ± 63.9
Lipid (g)	61.1 ± 31.2	62.8 ± 26.4
Protein (g)	64.1 ± 16.4	63.8 ± 22.0
Carbohydrate (%)	41.7 ± 6.9	40.9 ± 7.8
Lipid (%)	35.9 ± 9.2	37.1 ± 8.4
Protein (%)	18.2 ± 6.3	17.8 ± 5.1
Individualized		
Calorie intake (kcal)	1539.2 ± 493.0	1555.8 ± 403.8
Carbohydrate (g)	168.2 ± 68.6	164.5 ± 57.2
Lipid (g)	68.6 ± 23.4	67.5 ± 13.6
Protein (g)	73.6 ± 36.6	64.8 ± 25.2
Carbohydrate (%)	43.1 ± 8.2	41.9 ± 6.7
Lipid (%)	40.7 ± 7.9	40.6 ± 8.1
Protein (%)	19.6 ± 10.6	16.5 ± 3.8

Values are mean ± SD

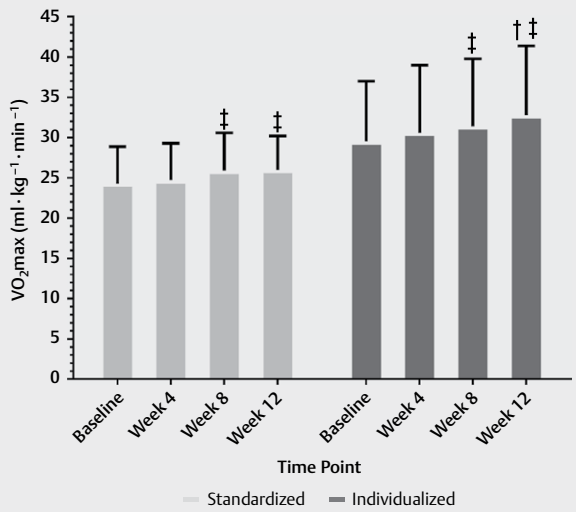
▶ **Table 3** Exercise prescription and progression for standardized and individualized exercise prescription based on percentage of heart rate reserve and ventilatory thresholds, respectively.

	Standardized				Individualized			
Week	**Target HR**	**Actual HR**	**Target Min**	**Actual Min**	**Target HR**	**Actual HR**	**Target Min**	**Actual Min**
1	108 ± 10 to 113 ± 11	113 ± 12	27 ± 6 to 32 ± 9	32 ± 9	105 ± 14 to 115 ± 14	114 ± 14	26 ± 6 to 31 ± 9	31 ± 8
2	108 ± 10 to 113 ± 11	113 ± 11	41 ± 10 to 48 ± 13	46 ± 11	105 ± 14 to 115 ± 14	114 ± 14	39 ± 10 to 47 ± 14	44 ± 9
3	108 ± 10 to 113 ± 11	114 ± 12	54 ± 13 to 64 ± 17	51 ± 10	105 ± 14 to 115 ± 14	114 ± 13	52 ± 13 to 63 ± 18	54 ± 9
4	118 ± 11 to 123 ± 11	120 ± 12	45 ± 8 to 49 ± 8	47 ± 8	122 ± 15 to 136 ± 15	131 ± 15	38 ± 8 to 48 ± 13	42 ± 9
5	124 ± 11 to 128 ± 11	126 ± 12	42 ± 8 to 47 ± 8	45 ± 7	122 ± 15 to 136 ± 15	134 ± 17	38 ± 8 to 48 ± 13	43 ± 9
6	124 ± 11 to 128 ± 11	127 ± 12	42 ± 8 to 47 ± 8	45 ± 7	122 ± 15 to 136 ± 15	135 ± 16	38 ± 8 to 48 ± 13	44 ± 9
7	124 ± 11 to 128 ± 11	127 ± 11	48 ± 9 to 53 ± 9	49 ± 7	122 ± 15 to 136 ± 15	133 ± 17	41 ± 8 to 52 ± 11	49 ± 9
8	124 ± 11 to 128 ± 11	127 ± 12	52 ± 10 to 58 ± 10	53 ± 8	125 ± 14 to 139 ± 15	134 ± 16	45 ± 8 to 57 ± 11	50 ± 9
9	129 ± 11 to 134 ± 12	131 ± 12	48 ± 8 to 53 ± 9	51 ± 8	144 ± 15 to 154 ± 15	149 ± 17	37 ± 9 to 42 ± 10	40 ± 10
10	129 ± 11 to 134 ± 12	132 ± 12	48 ± 8 to 53 ± 9	50 ± 7	144 ± 15 to 154 ± 15	148 ± 17	37 ± 9 to 42 ± 10	40 ± 10
11	129 ± 11 to 134 ± 12	133 ± 11	53 ± 9 to 59 ± 9	53 ± 6	144 ± 15 to 154 ± 15	148 ± 17	41 ± 10 to 47 ± 11	44 ± 10
12	129 ± 11 to 134 ± 12	133 ± 13	53 ± 9 to 59 ± 9	53 ± 6	144 ± 15 to 154 ± 15	147 ± 17	41 ± 10 to 47 ± 11	45 ± 10

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.

old [24]. Similarly, 22 and 78 % of participants exceeded the individual lactate threshold at 60 and 75 % of VO_2max, respectively. Some participants were above and others below the lactate threshold at a workload associated with 70 ± 1 % of VO_2R [36]. Furthermore, Azevedo et al. [4] found the ventilatory threshold occurred at 78 ± 7 % HR_{max} and 70 ± 10 % HRR. Based on these findings, it can be implied that workloads established with the use of the relative percent method increases variability in the metabolic response to exercise. Based on our current findings, we found that when steady-state aerobic exercise is prescribed on an individual basis using VT1 and VT2 as points to base exercise intensity and progression, there was a superior interaction between VO_2max and time point compared to the standardized group. We believe this is due to taking into consideration individual metabolic characteristics with the exercise prescription and the relative percent intensity providing variation in metabolic demands due to the exercise intensity prescription [23].

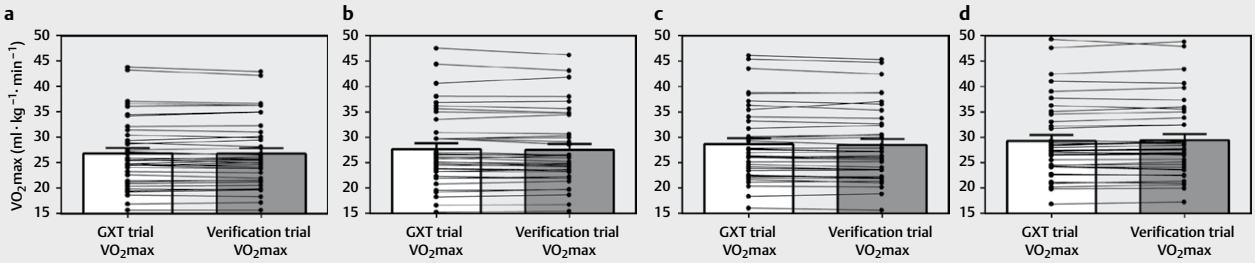
From a practical standpoint, it could be suggested that either the use of an isocaloric dose of steady-state aerobic exercise using HRR or threshold measures can increase VO_2max following 12 weeks of CRF training. However, it should be noted that the individualized training group using ventilatory thresholds provided more rapid and greater change in VO_2max. Such training might therefore underpin its potential relatively greater efficacy for prescription 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 completed based on threshold measurements to take into consideration individual metabolic characteristics and enhance training adaptations. Furthermore, based on our data, if aerobic training adaptations are not observed after 8 weeks of steady-state aerobic training, modifying the exercise prescription intensity or method of intensity prescription (i. e., changing from a relative percent method to an individualized method) should be considered to achieve the desired results.



▶ **Fig. 1** Group relative VO_2max at baseline, week 4, week 8, and week 12 for standardized and individualized exercise prescription. †Significantly different from previous time point; ‡significantly different from baseline.

Limitations

A potential risk for selection bias exists in the present study because the principal investigator was aware to which treatment group participants were allocated and also performed all GXT and verification protocol testing. However, the application of the verification protocol likely minimized any potential selection bias due to its robustness for verifying 'true VO_2max.' Even though the participants included in the study represent a standard exercise clinic demographic, 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_2max values with the individualized group having higher values. However, although not statistically significant, based on the results of the study the individualized group improved greater 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_2max) changes. Future studies should take into consideration these limitations to further address the time course changes in these exercise intensity 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. 2** Comparison of mean GXT trial VO_2max and verification trial VO_2max and individual (39 participants) VO_2max data represented by the line graphs at baseline **a**, week 4 **b**, week 8 **c**, and week 12 **d**.

▶ **Table 4** Graded maximal exercise test and verification protocol speed, grade, and duration for baseline, week 4, week 8, and week 12 testing.

		Standardized		Individualized		Group	
Time Point	**Parameter**	**GXT**	**Verification**	**GXT**	**Verification**	**GXT**	**Verification**
Baseline	**Speed (km · $^{-1}$)**	5.2 ± 0.9	5.2 ± 0.9	6.1 ± 1.4	6.1 ± 1.4	5.6 ± 1.3	5.7 ± 1.3
	Grade (%)	10.7 ± 2.7	11.4 ± 2.7	10.5 ± 2.7	11.2 ± 2.6	10.6 ± 2.7	11.3 ± 2.6
	Duration (sec)	684.8 ± 127.3	148.5 ± 28.3	672.6 ± 147.8	147.6 ± 38.8	678.8 ± 136.0	148.1 ± 33.4
Week 4	**Speed (km · $^{-1}$)**	5.4 ± 0.8	5.5 ± 0.7	6.1 ± 1.3	6.2 ± 1.3	5.7 ± 1.1	5.8 ± 1.1
	Grade (%)	10.0 ± 2.0	10.7 ± 1.8	12.0 ± 3.3	12.7 ± 3.2	11.0 ± 2.9	11.7 ± 2.7
	Duration (sec)	654.0 ± 111.7	154.5 ± 33.0	665.5 ± 137.5	145.3 ± 27.9	659.6 ± 123.4	150.0 ± 30.6
Week 8	**Speed (km · $^{-1}$)**	5.5 ± 0.7	5.5 ± 0.7	6.1 ± 1.5	6.2 ± 1.5	5.8 ± 1.2	5.8 ± 1.2
	Grade (%)	10.0 ± 1.4	10.9 ± 1.3	12.1 ± 3.2	12.8 ± 3.0	11.0 ± 2.6	11.8 ± 2.4
	Duration (sec)	638.3 ± 62.4	141.8 ± 32.1	675.0 ± 114.0	148.4 ± 29.1	656.2 ± 91.9	145.0 ± 30.5
Week 12	**Speed (km · $^{-1}$)**	5.6 ± 0.8	5.6 ± 0.8	6.6 ± 1.8	6.7 ± 1.8	6.1 ± 1.4	6.1 ± 1.5
	Grade (%)	10.3 ± 1.4	11.2 ± 1.4	10.5 ± 3.0	11.3 ± 2.8	10.4 ± 2.3	11.2 ± 2.1
	Duration (sec)	681.8 ± 81.2	143.3 ± 35.6	652.9 ± 142.6	168.2 ± 31.1	667.7 ± 114.6	155.4 ± 35.3

Values are mean ± SD. GXT, graded exercise test.

plore 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_2max 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_2max 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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