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Research article

The Impact of Personalized versus Standardized Cardiorespiratory and Muscular Training on Health-Related Outcomes and Rate of Responders

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Abstract
Recent research has shown more favorable training adaptations for inactive adults when cardiorespiratory fitness (CRF) exercise is prescribed with the use of ventilatory thresholds compared to percentages of heart rate reserve (HRR). However, there is limited research on changes in health-related outcomes with the use of these CRF methods in combination with muscular fitness exercises. The objective of this study was to compare the effectiveness of two training programs for improving CRF, muscular fitness, and cardiometabolic risk factors. Inactive men and women (n=109, aged 49.3±15.5 years) were randomized to a non-exercise control group or one of two exercise training groups. The exercise training groups consisted of 13 weeks of structured exercise with progression using either CRF exercise prescribed with the use of ventilatory thresholds and functional training for muscular fitness (THRESH group) or HRR and traditional muscular fitness training (STND group). After the 13-week protocol, there were significant differences in body weight, body composition, systolic blood pressure, high-density lipoprotein cholesterol (HDL-c), VO_2max, 5-repetition maximum (RM) bench press, and 5-RM leg press for both treatment groups compared to the control group after controlling for baseline values. However, the THRESH group had significantly more desirable outcomes for VO_2max, 5-RM bench press, 5-RM leg press, body composition, and HDL-c when compared to both the STND and control group. Additionally, the proportion of individuals estimated as likely to respond above 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ in VO_2max (i.e., the minimal clinically important difference) was 76.4%, 20.8%, and 0.13% for the THRESH, STND, and control groups, respectively. While both exercise programs elicited favorable health-related adaptations after 13 weeks, these results suggest that a personalized program with exercise prescribed based on ventilatory threshold and with the use of functional muscular fitness training may yield greater training adaptations.

Key words: Exercise training, VO_2max, muscular fitness, training responsiveness.

Introduction

Exercise prescription is primarily anchored to the frequency, intensity, time, and type of exercises associated with cardiorespiratory and resistance activities in an effort to improve various health outcomes (Liguori and American College of Sports Medicine, 2021). It has been found that an increase in cardiorespiratory fitness (CRF) by 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ is the minimal clinically important difference (MCID) (Ross et al., 2016; Bonafiglia et al., 2022) and an improvement of 1–2 metabolic equivalents (METs) is associated with a reduction in adverse cardiovascular events by 10–30% (Ross et al., 2016). Furthermore, findings from a systematic review and meta-analysis suggest adults with higher muscular strength levels have a 31% reduced risk of all-cause mortality and a 14% lower risk of death based on handgrip and knee extension strength, respectively (García-Hermoso et al., 2018). Taking into consideration the robust amount of literature in this topical area and the encouragement of incorporating both modalities into an exercise prescription from major health/exercise/fitness organizations (Garber et al., 2011; American Council on Exercise, 2020; Liguori and American College of Sports Medicine, 2021), cardiorespiratory and muscular exercise can be prescribed to inactive adults to improve fitness and overall health.

Previous findings have shown considerable heterogeneity in CRF responses (i.e., measures of maximal oxygen uptake [VO_2max]) following an exercise intervention. Indeed, some individuals exhibit large improvements whereas others have minimal or, in some instances, a decline in CRF (Skinner et al., 2000; Scharhag-Rosenberger et al., 2010; 2012; Weatherwax et al., 2019). Recently, it was found that 10 weeks of CRF training at 55% of HRR resulted in only half (52%) of the participants categorized as a VO_2max responder (defined as a responder when VO_2max changes were greater than technical measurement error) and no further changes were noted in VO_2max responsiveness following a subsequent 16 week block of training at the same intensity (Reuter et al., 2023). In the same study, it was reported that training at a higher CRF intensity (going from 55% HRR to 95% HR_{max}) with the same energy expenditure increased the rate of VO_2max responsiveness. These findings are paradoxical to other research (Katch et al., 1978; Weatherwax et al., 2019) that have suggested the variability in responsiveness may largely be due to the prescribed exercise intensity not taking into consideration individual metabolic considerations when more traditional approaches to CRF exercise intensity prescription are used, such as percentages of HRR leading to the potential over- or under-training of participants. Jamnick and colleagues (2020) noted in their narrative review on methods to determine exercise intensities that reserve methods (i.e., HRR) should not be recommended as valid approaches to identify consistent exercise intensities across individuals due to a lack in “domain-specific homeostatic perturbations.” Therefore, it has been suggested that CRF intensity be anchored with the use of thresholds (i.e., ventilatory or lactate) to have a more consistent homeostatic stress, improve individual training

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adaptations, and demarcate between light, moderate, and vigorous intensities (Wolpern et al., 2015; Dalleck et al., 2016; Weatherwax et al., 2019).

The American Council on Exercise (ACE) has adopted the use of ventilatory thresholds in combination with a multiplanar/functional resistance training approach as key considerations in their Integrated Fitness Training model to incorporate a more personalized exercise prescription (American Council on Exercise, 2020). Functional based training has gained popularity (Silva-Grigoletto et al., 2020) with a central theme of emphasizing natural movements (Weiss et al., 2010; Tomljanović et al., 2011). While specific definitions are broad spanning, functional training has been defined as purposeful learning (Boyle, 2016) that is individualized and the general outcome is improved movement with a focus on movement patterns in multiple planes rather than individual muscles (Stenger, 2018). Functional training has been found to elicit equitable improvements in strength outcomes when compared to traditional resistance training in untrained adults (Zuo et al., 2022), young adults (Weiss et al., 2010), and older women (De Resende-Neto et al., 2019). However, when compared to traditional resistance training, functional training in men and women has been found to require a higher caloric expenditure (Lagally et al., 2009) and significantly improve basal metabolic rate in previously sedentary women (Stavres et al., 2018). Therefore, functional training could complement a threshold-based cardiorespiratory exercise prescription to further stimulate advantageous adaptations in cardiorespiratory and cardiometabolic factors to enhance health-related outcomes.

The purpose of this study was to compare the effectiveness of two training programs for improving CRF, muscular fitness, and cardiometabolic risk factors: a standardized program with CRF intensity determined based on HRR and resistance exercise prescribed with a standardized muscle group emphasis versus a more personalized and threshold-based model with CRF intensity anchored to ventilatory thresholds and functional based training for resistance exercise. These training paradigms have been incorporated to mimic real-world exercise prescription scenarios and to compare changes in common health and fitness-related measures following a commonly implemented standardized-based program versus a threshold/personalized approach. It was hypothesized that given the personalized approach, the threshold model would elicit greater improvements in the main health-related outcome variables, along with more likely CRF responders, relative to the standardized program.

Methods

Participants

Non-smoking men and women (n=109, aged 49.3±15.5 years) between ages 18-64 years who indicated they did not participate in regular exercise and verbally agreed to maintain habitual dietary habits were recruited from the community to participate in the study. Exclusion criteria included evidence (diagnosed or signs/symptoms) of cardiovascular, metabolic, or renal disease (Liguori and American College of Sports Medicine, 2021). All participants provided written informed consent. This study was approved by the University Human Research Committee (HRC2017-02-03-R28).

Baseline and post-program testing procedures

Measurements of all outcome variables were completed on two non-consecutive days and followed standardized protocols provided in detail elsewhere (American Council on Exercise, 2020; Liguori and American College of Sports Medicine, 2021). A brief overview of procedures for each measurement are included below. Participants were instructed to fast for 12 hours prior to the first testing session and refrain from strenuous exertion for 12 hours prior to both testing sessions. Post-testing occurred within 1-4 days following the completion of the final exercise training session.

Seated heart rate and blood pressure: Participants sat quietly for 5 minutes (min) in a chair with back support, legs uncrossed with feet on the floor, and arms supported at near heart level prior to measurements. Seated heart rate (HR) was obtained via manual palpation of radial artery in the left wrist and recording the number of beats for 60 seconds. The left arm brachial artery systolic and diastolic blood pressure (BP) were measured manually using a sphygmomanometer in duplicate, separated by 1-min, and averaged.

Anthropometric measurements: Participants were weighed to the nearest 0.1 kilograms (kg) on a medical grade scale and measured for height to the nearest 0.5 centimeters (cm) using a stadiometer. Percent body fat was determined via a 3-site skinfold assessment using published protocols (Liguori and American College of Sports Medicine, 2021). Skinfold assessments were completed using a Lange caliper (Cambridge Scientific Industries, Columbia, MD). Skinfold thickness was measured to the nearest ± 0.5 millimeters (mm) on the right side of the body using standardized anatomical sites including the chest, abdomen, and thigh for males and triceps, suprailiac, and thigh for females. These measurements were performed until two measurements were within 1-2 mm of each other. Waist circumference was measured horizontally at the narrowest point of the torso between the xiphoid process and umbilicus using a Gulick-type spring loaded-handle (Creative Health Products, Ann Arbor, MI). Measurements were taken until two measurements within 0.5 mm of each other were obtained.

Fasting blood lipid and blood glucose measurement: A small sample of blood (40 uL) from the finger was collected and immediately analyzed to obtain fasting total cholesterol (TC), high density lipoprotein cholesterol (HDL-c), low density lipoprotein cholesterol (LDL-c), triglycerides (TRG), and blood glucose using the Cholestech LDX System (Alere Inc., Waltham, MA) test. All blood collection and analysis procedures were performed while strictly adhering to the manufacturer's instructions.

Muscular fitness assessments: Procedures for muscular fitness assessment outlined previously were followed (American Council on Exercise, 2020). In summary, five-repetition maximum (5-RM) testing for the bench press and leg press exercises were performed using the following protocol:

1. 10 repetitions of a weight the participant felt comfortable lifting (40-60% of estimated 5-RM) were performed to warm up muscles followed by 1-min rest period
2. 5 repetitions at weight of 60-80% estimated 5-RM was performed as a further warm up and followed by a 2-min rest period
3. The first 5-RM attempt at weight of 2.5-20kg greater then warm up

- Upon successful completion of the first 5-RM lift with appropriate lifting form and a 3-5 min rest following the attempt, weight was increased by 5-10% and 10-20% for bench press and leg press, respectively. This protocol was repeated until a 5-RM was achieved with no more than 3 x 5-RM attempts.
- If the first 5-RM lift was deemed unsuccessful by the researcher, weight was decreased by 5-10% and 10-20% for bench press and leg press, respectively, until the participant successfully lifted the heaviest weight possible.

Maximal exercise testing: A customized graded exercise test (GXT) ramp protocol on a motorized treadmill (Powerjog GX200, Maine, USA) was used to test VO_2max and assess gas exchange data. Participants walked or jogged at a self-selected pace that was maintained throughout the duration of the test while incline was increased by 1% every minute until volitional exhaustion was reached. Participant HR was continuously recorded throughout the GXT using a chest strap and radio-telemetric receiver (Polar Electro, Woodbury, NY, USA). Expired air and gas exchange data were recorded continuously during the GXT using a metabolic analyzer (Parvo Medics TrueOne 2.0, Salt Lake City, UT, USA). Before each exercise test, the metabolic analyzer was calibrated in accordance with manufacturer guidelines. Breath-by-breath data were averaged for every 15 sec. The final two consecutive 15 sec data were averaged to represent the data at VO_2max. The criteria for the attainment of VO_2max were two out of three of the following: (1) A plateau ($\Delta VO_2 < 150$ mL/min) in VO_2 with increases in workload, (2) maximal respiratory exchange ratio (RER) > 1.1, and (3) maximal HR within 10 beats/min of the age-predicted maximum (220—age). Maximal HR was the highest recorded HR at the end of the GXT. HRR was determined by taking the difference between maximal HR and seated HR.

Determination of ventilatory thresholds: Determination of the first ventilatory threshold (VT1) and second ventilatory threshold (VT2) was made by graphing and visually inspecting time plotted against each relevant respiratory variable (according to 15 sec time-averaging). The criteria for VT1 was an increase in VE/VO_2 with no concurrent increase in VE/VCO_2 and departure from the linearity of VE. The criteria for VT2 was a simultaneous increase in both VE/VO_2 and VE/VCO_2. All assessments were completed by two experienced exercise physiologists. In the event of conflicting results, the original assessments were reevaluated and collectively a consensus was agreed upon.

Exercise protocol

Participants were randomized after the completion of baseline testing to a non-exercise control group or one of two exercise training groups according to a computer-generated sequence of random numbers that was stratified by sex. This was a double-blind research design in that participants were unaware of the group to which they had been assigned. Likewise, the researchers specifically responsible for testing and supervision of exercise sessions were unaware of the group to which participants had been allocated. Participants randomized to the exercise training groups performed 13 weeks of exercise training according to one of two programs: 1) the threshold and functional training program (THRESH), or 2) a standardized program (STND). Each exercise training group performed a similar frequency and duration of exercise training and were intended to fulfill the consensus recommendation of 150 $min \cdot wk^{-1}$.

Cardiorespiratory exercise prescription: Cardiorespiratory training was performed on various aerobic modalities: arm, cycle, and rowing ergometers; elliptical cross trainer, and treadmill. The STND group was prescribed exercise intensity according to a percentage of HRR for inactive participants based on current exercise prescription guidelines (Garber et al., 2011; Liguori and American College of Sports Medicine, 2021). Ventilatory thresholds were used as anchors for CRF intensity in the THRESH group (American Council on Exercise, 2020). A target HR range related to either the prescribed HRR or prescribed proximity to VTs was used to establish a specific exercise training intensity for each exercise session and progressed as follows for the STND group:

- Wk 1-4: target HR = 40-45% of HRR
- Wk 5-8: target HR = 50-55% of HRR
- Wk 9-13: 60-65% of HRR

Progression of HR intensity for THRESH group was established in the following manner:

- Wk 1-4 (HR < VT1): target HR = HR range of 10-15 bpm just below VT1
- Wk 5-8 (HR ≥ VT1 to < VT2): target HR = HR range of 10-20 bpm above VT1 and below VT2
- Wk 9-13 (HR ≥ VT2): target HR =HR range of 10-15 bpm at or just above VT2

Polar HR monitors (Polar Electro Inc., Woodbury, NY, USA) were used to monitor HR during all exercise sessions. Workloads were adjusted on aerobic modalities accordingly during each exercise session to ensure prescribed and actual HR measures were aligned.

Resistance exercise prescription: Participants began resistance/functional training on 3 $d \cdot wk^{-1}$ starting during week 4 of the training program. All sessions were closely monitored and supervised by the research team to ensure adherence, proper technique, and provided specific information on progression based on the exercise prescription for each group.

The resistance training program for the STND group was designed according to established guidelines and consisted of single and multi-joint exercises completed using machine modalities commonly found at most fitness facilities to target each major muscle group (Garber et al., 2011; Liguori and American College of Sports Medicine, 2021). In summary, the following exercises were performed: bench press, shoulder press, lateral pulldown, seated row, bicep curl, triceps pushdown, seated leg press, seated leg extension, prone lying leg curl, and seated back extension/flexion. For the THRESH group, the resistance training program was prescribed according to current recommendations and guidelines for functional training (American Council on Exercise, 2020) and consisted of multijoint/multiplanar exercises completed using free weight and machine modalities. The machine modalities that were used allowed for free motion during the exercise and therefore range of motion was not fixed or limited based on the exercise machine settings. The following exercises were performed in the THRESH group: stability ball circuit (hip bridges, crunches, Russian twists, planks), lunge matrix, kneeling/standing wood chops, kneeling/standing hay bailers, dumbbell squat to 90-degree knee bend, standing one-arm cable row, step-ups with dumbbell onto 15cm step, modified (assisted) pull-ups, and dumbbell bench press.

Two sets of 12 repetitions were completed for each exercise. Intensity of weighted exercises started at 50% 5-RM and progressed by 5% 5-RM increments every 2 weeks. For exercises that did not include an externally weighted resistance (e.g. stability ball circuit, modified pull-ups), the volume of each exercise in the form of repetitions was increased by ~5-10% to maintain an RPE rating of 5–6 (Sweet et al., 2004).

Statistical analysis

Descriptive statistics are reported as mean ± standard deviation (SD) and n (%) for continuous and categorical variables, respectively. One-way ANOVAs were used to determine whether the groups differed by any of the measured variables at baseline. ANCOVAs were used to determine whether there were differences between the groups post intervention for all of the outcome variables while controlling for baseline values. A Bonferroni correction was used to correct for multiple comparisons when ANCOVA results were statistically significant. Statistical significance was determined as $p<0.05$. Partial eta squared ($p\eta^2$) effect sizes were interpreted as: 0.01, small effect; 0.06, medium effect; 0.14, large effect.

To assess treatment response heterogeneity for CRF of the interventions, we calculated the standard deviation for individual responses (SD_{IR}). The SD_{IR} is defined as the difference between the standard deviations of the changes in intervention and control groups and is calculated as follows: $SD_{IR}=\sqrt{(SDexp^2\text{-}SDcon^2)}$ (Hrubeniuk et al., 2021). To determine the magnitude of exercise treatment response heterogeneity for CRF, we standardized the SD_{IR} by dividing the SD_{IR} by the SD of all subjects' VO_2max values at baseline (Hrubeniuk et al., 2021). The standardized SD_{IR} was then interpreted as: 0.1, small; 0.3, moderate; 0.6, large; 1.0, very large; and 2.0, extremely large (Hopkins, 2015). Finally, we estimated the proportion of likely responders as suggested by Atkinson and colleagues (2019) by entering the mean treatment response and SD for each of the intervention groups into an online calculator (http://onlinestatbook.com/2/calculators/normal_dist.html) to find the area under the curve (AUC) above the MCID threshold for CRF of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$.

Results

Participant characteristics

The sample consisted of n=109 middle-aged (49.3±15.5 y), overweight (BMI: 27.0±4.8 kg/m^2; body fat: 29.7±7.0%) adults (women: 51.4%, n=56). Participants generally had VO_2max values classified as average to below average (29.0±7.8 $mL \cdot kg^{-1} \cdot min^{-1}$), and had normal levels of systolic BP (SBP: 118±11 mmHg), diastolic BP (DBP: 79±8 mmHg), and fasting lipids (TC: 197±41 mg/dL; HDL-c: 55±18 mg/dL; LDL-c: 117±36 mg/dL; TRG:119±52 mg/dL) and blood glucose (93±8 mg/dL) at baseline. There were differences in waist circumference, systolic blood pressure, body composition, and fasting glucose between the groups at baseline ($p<0.05$). Results for the measured variables at baseline and post intervention for each group are displayed in Table 1.

Table 1. Outcome variables for each of the three groups at baseline and post-intervention.

Variable	Control (n=35)		THRESH (n=37)		STND (n=37)	
	Pre	Post	Pre	Post	Pre	Post
VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	29.8±6.3	29.5±6.2	29.5±7.1	34.3±7.6‡	27.8±9.5	30.0±10.1†
Resting HR (bpm)	65±11	66±9	68±9	67±11	69±10	68±10
5-RM bench press (kg)	29±22	29±21	28±20	35±25†	28±21	33±24†
5-RM leg press (kg)	86±74	86±70	81±57	111±73‡	80±63	98±72†
Weight (kg)	71.9±10	72.4±9.7	80.2±18.4	79.3±17.8†	77.9±16.0	77.3±15.8†
Body composition (%)	27.3±3.4*	28.5±3.8	31.0±8.3	26.8±7.1‡	30.7±7.5	27.9±5.9†
Waist circumference (cm)	80.3±7.0*	80.7±6.8	88.9±14.1	86.2±11.6	87.6±14.8	87.4±12.0
Systolic blood pressure (mmHg)	115±9*	118±8	121±10	116±8†	118±12	116±12†
Diastolic blood pressure (mmHg)	77±8	81±7	80±8	77±7†	80±8	80±9
Total cholesterol (mg/dL)	188±32	191±27	206±39	203±40	198±48	208±51
LDL-c (mg/dL)	108±30	108±28	120±33	117±29	121±42	123±38
HDL-c (mg/dL)	55±23	54±20	56±17	61±16‡	55±15	57±14†
Triglycerides (mg/dL)	117±41	122±41	117±43	103±38†	123±68	117±62
Glucose (mg/dL)	90±7*	91±8	96±8	91±6†	93±9	92±9

Values are reported as mean ± standard deviation; THRESH, threshold and functional training group; STND, standardized program; VO_2max, maximal oxygen consumption; LDL-c, low-density lipoprotein; HDL-c, high-density lipoprotein; for LDL-c pre, n=30; for LDL-c post, n=31 for the control group. * statistically significant difference between all groups at baseline ($p<0.05$). † statistically significant difference between control group post-intervention after controlling for baseline value ($p<0.05$). ‡ statistically significant difference between control and standardized group after controlling for baseline value ($p<0.05$).

Health-related fitness components

There were statistically significant effects for: VO_2max ($F(2,105)=91.0$, $p<0.001$, $p\eta^2=0.63$), 5-RM bench press ($F(2,105)=33.6$, $p<0.001$, $p\eta^2=0.39$, and 5-RM leg press ($F(2,105)=29.5$, $p<0.001$, $p\eta^2=0.36$) when controlling for baseline measurements. Post-testing measurements were significantly different between the groups for all of the health-related fitness variables (Table 1). Participants who underwent THRESH programming experienced the largest improvements in health-related fitness variables compared to participants in the STND group and the control group. Specifically, participants in the THRESH and STND groups improved their VO_2max on average, by 17.2±7.1% and 8.6±8.1%, respectively (Figure 1). There were no differences in seated HR post-intervention between the groups after controlling for baseline seated HR ($F(2,105)=0.03$, $p=0.97$, $p\eta^2=0.001$).

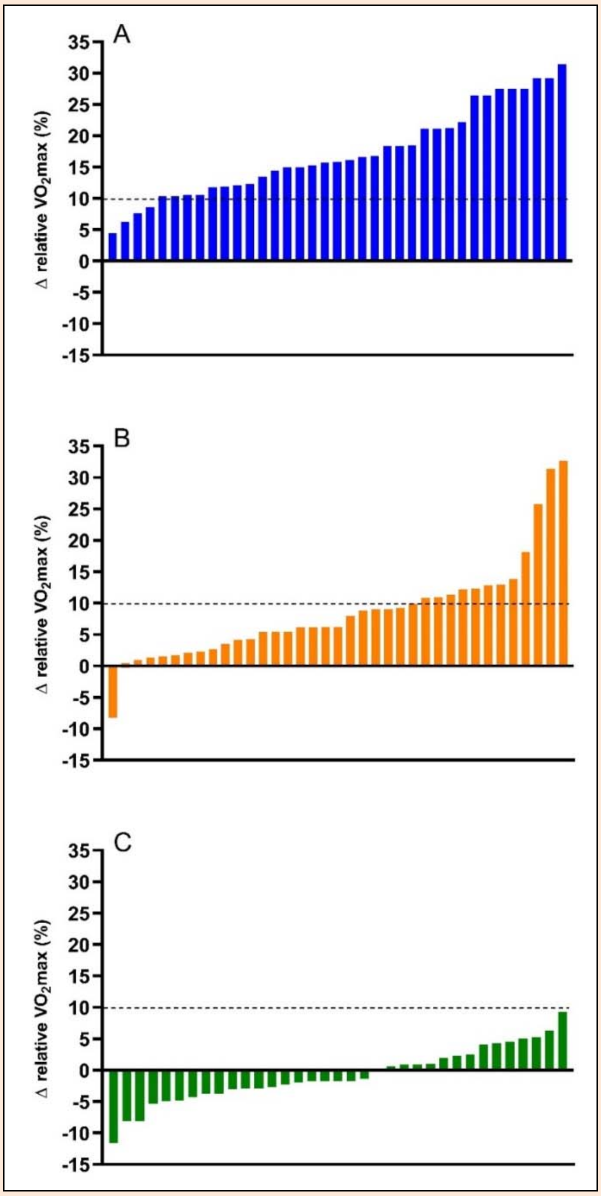

Figure 1. Changes in percent VO_2max for individual participants in A) the THRESH, B) STND, and C) Control groups. The horizontal black dashed line at 10% represents the demarcation for clinical meaningfulness in changes in percent VO_2max.

Minimal clinically important difference

The proportion of individuals exceeding the MCID (i.e., improvement in VO_2max >3.5 $mL \cdot kg^{-1} \cdot min^{-1}$or 1 MET) can be found in Figure 2. In summary, the majority of participants in the THRESH group (n=25, 67.6%) improved VO_2max by more than 1 MET whereas n=9 (24.3%) in the STND group improved beyond 1 MET. None of the participants in the control group exceeded the threshold for a meaningful improvement in VO_2max of 1 MET or greater.

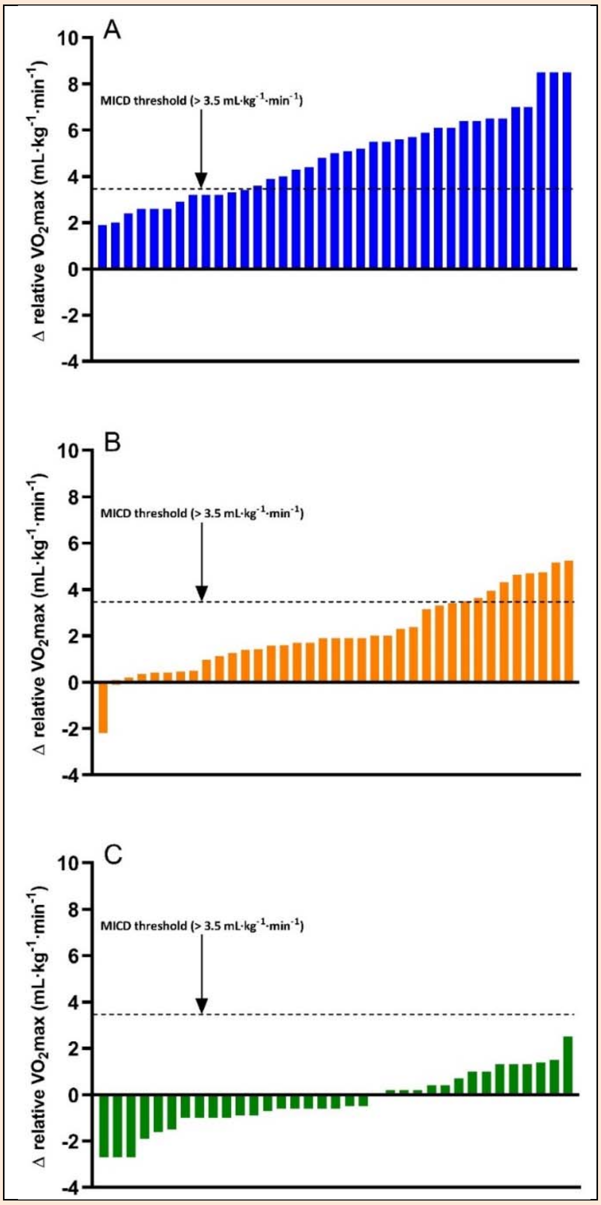

Figure 2. Changes in relative VO_2max for individual participants in A) the THRESH, B) STND, and C) Control groups. The horizontal black dashed line at 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ represents the minimal clinically important difference (MCID) threshold for changes in cardiorespiratory fitness.

Heterogeneity of treatment response and proportion of likely responders

The SD_{IR} values for the change in VO_2max for the THRESH and STND intervention groups were 1.36 and 1.10 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. Standardizing the SD_{IR} values to all participants' baseline VO_2max values resulted in a value of 0.18 and 0.14 for the THRESH and STND groups, respectively, indicating there was small exercise treatment response heterogeneity for participants in both of the groups. The proportion of individuals in the population estimated as likely to respond above the MCID threshold for cardiorespiratory fitness of 1 MET to the THRESH, STND, and control group was 76.4% (SD_{IR}=1.36 mL·kg^{-1}·min^{-1}), 20.8% (SD_{IR}=1.10 mL·kg^{-1}·min^{-1}), and 0.13%, respectively.

Cardiometabolic disease risk factors

There were differences between the groups for weight ($F(2,105)=7.3$, $p<0.001$, $p\eta^2=0.12$) and body composition ($F(2,105)=43.7$, $p<0.001$, $p\eta^2=0.45$) post-intervention, when controlling for baseline measures. On average, participants' weight was significantly lower between the control group and intervention groups post-intervention; there was no difference in weight post-intervention between the THRESH and STND groups. Body composition was significantly different between all groups post-intervention; participants in the THRESH group had the lowest percent body fat, whereas participants in the control group had the highest percent body fat post-intervention. There were no differences in waist circumference post-intervention between the groups after controlling for baseline waist circumference ($F(2,105)=16$, $p=0.20$, $p\eta^2=0.03$).

There was a difference in SBP ($F(2,105)=9.7$, $p<0.001$, $p\eta^2=0.16$) and DBP ($F(2,105)=6.5$, $p=0.002$, $p\eta^2=0.11$) between the groups when controlling for BP at baseline. On average, participants who underwent THRESH or STND programming had significantly lower SBP post-intervention compared to participants in the control group; there was no difference in SBP between participants in the THRESH or STND group post-intervention. Participants in the THRESH group had significantly lower DBP post-intervention compared to the control group, however, there was no difference in DBP post-intervention between the THRESH and STND group, as well as between the STND and control group.

There were differences between fasting TC ($F(2,105)=3.9$, $p=0.02$, $p\eta^2=0.07$), LDL-c ($F(2,105)=3.4$, $p=0.04$, HLD-c ($F(2,105)=21.2$, $p<0.001$, $p\eta^2=0.29$), TRG ($F(2,105)=9.6$, $p<0.001$, $p\eta^2=0.15$), and glucose ($F(2,105)=15.7$, $p<0.001$, $p\eta^2=0.23$). On average, fasting lipid profile and glucose improved to the greatest extent in participants who underwent THRESH programming. Participants who underwent STND programming saw slight improvements to HDL-c and TRG, but also showed increases in TC and LDL-c. Participants in the control group had slightly worse fasting lipid profiles and glucose post-intervention.

Discussion

This study investigated the effectiveness of personalized exercise programming using ventilatory thresholds for cardiorespiratory exercise and functional training compared to more traditional approaches using standardized exercise prescription methodologies. Positive adaptations in health-related outcomes were found in both groups. However, the THRESH group had more favorable and significant adaptations in VO_2max, upper and lower body strength as measured by 5-RM, body composition, and HDL-c. Furthermore, the estimated likely responders for VO_2max changes were considerably higher (76.4% versus 20.8%) in the THRESH group compared to the STND group. These results support our research hypothesis and emphasize the importance of a more personalized approach to exercise prescription to further enhance training efficacy and health-related outcomes in inactive adults. To our knowledge, only one other investigation has explored this methodology and exhibited similar findings (Dalleck et al., 2016). However, the current investigation included a more robust sample size and implemented currently accepted approaches to explore training responsiveness.

One finding in the current investigation was a greater increase in VO_2max in both experimental groups compared to the control group. This is an important finding to underpin the importance of engaging in some form of exercise/activity to increase the likeliness to elicit positive adaptions. However, it is even more notable that significantly greater increases in VO_2max were shown in the THRESH group compared to the STND group. The THRESH group increased VO_2max by 4.85±1.9 mL·kg^{-1}·min^{-1} (17.2 ± 7.1%) whereas the STND group had an increase of 3.1±1.7 mL·kg^{-1}·min^{-1} (8.6 ± 8.1%). These VO_2max improvements and group differences are similar to previous CRF trainability findings comparing cardiorespiratory exercise anchored to standardized methods (i.e., HRR) versus personalized methods (i.e., ventilatory thresholds) (Wolpern et al., 2015; Dalleck et al., 2016; Weatherwax et al., 2019). Furthermore, the THRESH group VO_2max changes in the present study are similar to CRF improvements (3.4 ± 2.7 mL·kg^{-1}·min^{-}) following a 26 week protocol with 3 d·wk^{-1} of CRF with an initial intensity or 55% HRR for 10 weeks, 70% HRR for the subsequent 8 weeks followed by a high-intensity interval training for the final 6 weeks at 95% HR_{max} (Reuter et al., 2023). It should be noted that changes in CRF fitness as measured by increases in VO_2max may not be solely dependent on the CRF exercise prescription and may also have been influenced by the muscular fitness exercises. While not specifically measured in the current study, we believe the influence of CRF improvements directly from the functional muscular fitness training were minimal. It was previously found that functional training performed in a similar manner as the current investigation elicited an increased energy expenditure but did not increase VO_2 values enough to exceed recommendations to improve CRF measures (Lagally et al., 2009).

With the growing support of the Exercise is Medicine movement (Thompson et al., 2020), there is an increased need to identify exercise modalities and prescription protocols that elicit favorable changes in various health outcomes for participants. There has been a growing body of literature suggesting that following the completion of an exercise intervention, some participants do not respond to the intervention and lack favorable changes for a specific variable of interest (Pickering and Kiely, 2019). However, caution has been advised when labeling participants as responders/non-responders due to the dichotomization of a continuous variable and loss in statistical power for specific threshold values to differentiate responsiveness (Atkinson et al., 2019). Therefore, instead of individual classification of responsiveness, the proportion of individual participants estimated to exceed the MCID were identified. Interestingly, the proportion of participants estimated to exceed the MCID (i.e., use of AUC approach outlined previously) in the THRESH group was 76.4% compared to 20.8% for the STND group. These increases in CRF fitness resulted in 67.6% (25 of 37) and 24.3% (9 of 37) of participants in the THRESH and STND groups, respectively, to exceed the MCID of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ and could be identified as likely responders to the intervention. These results are similar to previous findings when ventilatory thresholds versus HRR were used for cardiorespiratory exercise intensity (Wolpern et al., 2015; Dalleck et al., 2016; Weatherwax et al., 2019). Specifically, the proportion of participants to have changes in VO_2max beyond the MCID for the threshold-based group compared to the standardized group were 46.3% and 17.0% (Weatherwax et al., 2019), 67.3% and 19.4% (Wolpern et al., 2015), and 51.9% and 21.9% (Dalleck et al., 2016), respectively. When evaluating the percent changes in VO_2max (Figure 1), in the THRESH group, 89.2% (33/37) of participants experienced a 10% or greater improvement in VO_2max. In contrast, only 32.4% (12/37) of participants in the STND group experienced a 10% or greater improvement. The almost universal ≥ 10% CRF improvements (N=33/37) observed in the THRESH group have substantial clinical meaningfulness as for each 10% improvement in CRF, there is a corresponding 15% reduction in the risk for mortality from CVD (Barlow et al., 2012). An approximate 10% increase in CRF has also been linked in previous studies to an increase in lifespan by about two years (Clausen et al., 2018). With these improvements observed in the current study, we contend the personalized approach of the THRESH group elicited a more homogenous response in terms of achieving a clinically meaningful outcome.

A recent retrospective analysis of over 850 participants of various CRF levels ranging from inactive to well-trained was explored to identify the relationship of the ventilatory threshold (i.e., VT1) in comparison to percentages of VO_2 reserve (VO_2R), HRR, and RPE (Gaskill et al., 2023). Interestingly, it was found participants had a ventilatory threshold at the lowest percentage of VO_2R when near a 'midrange' VO_2peak of 40 $mL \cdot kg^{-1} \cdot min^{-1}$. Furthermore, the ventilatory threshold (as a percentage of VO_2R) increased as VO_2peak progressed below and above 40 $mL \cdot kg^{-1} \cdot min^{-1}$. Additionally, it was reported that when ventilatory threshold was identified as a percentage of VO_2R, ventilatory threshold ranged from 33-78% and 42-87% of VO_2R for participants with a VO_2peak near 40 $mL \cdot kg^{-1} \cdot min^{-1}$ and 20 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. When considering that common activities of daily living have an energy expenditure of approximately 4 to 5 METs (i.e., a VO_2 of 14-17.5 $mL \cdot kg^{-1} \cdot min^{-1}$) (Garber et al., 2011), individuals who are less fit might have adaptations to their VT1 occur at a higher percentage of maximal abilities simply by performing activities of daily living. These findings are notable, especially for our current population in which only 4 participants in the STND group exceeded a VO_2max of 40 $mL \cdot kg^{-1} \cdot min^{-1}$ at baseline. If we operate under the assumption that percentage of VO_2R and HRR are related (Liguori and American College of Sports Medicine, 2021), participants within the STND group likely did not have enough stimulus for greater adaptations since the prescribed percentage of HRR likely did not exceed their first ventilatory threshold. Indeed, the CRF intensity within the THRESH group ultimately was prescribed at a higher intensity when compared to the STND with a mean %HRR of 56.9% and 61.7% for the STND and THRESH groups, respectively. This higher %HRR in the THRESH group was based on intensity determined by ventilatory thresholds rather than the specific relative percent methods implemented in the STND group. The THRESH group CRF intensities were specific to the individual ventilatory characteristics and, therefore, these higher values are likely a natural byproduct of the methodology used within the THRESH group. Therefore, the use of ventilatory thresholds as an anchor point to demarcate differing training intensities may be a more effective approach for setting minimum and maximum boundaries to training zones compared to the use of HRR.

One factor that has not been accounted for within the current investigation, nor any of the previous studies investigating differences in ventilatory thresholds and percentages of HRR, to our knowledge, is the variable relationship between VO_2 and HR, especially as cardiovascular drift increasingly dissociates the VO_2 and HR response during prolonged cardiorespiratory training (Teso et al., 2022). Recently, Iannetta and colleagues (2023) explored the efficacy of using the HR at the respiratory compensation point (i.e., VT2) from a GXT and found the associated HR poorly corresponded to the maximal metabolic state when exercise at this intensity exceeded 10 minutes in duration. In fact, it was found these differences became progressively larger when exercise at the maximal metabolic steady state was performed up to 30 minutes. These findings could have important implications as exercise prescription based on thresholds derived from a GXT may not necessarily be more personalized but rather induce a greater relative cardiorespiratory training stimulus that ultimately yields greater adaptations in CRF (Iannetta et al., 2023).

Another important finding from the current investigation was a greater increase in muscular fitness outcomes, measured by increases in 5-RM bench and leg press exercises, for both experimental groups. These findings were similar to those previously reported in which both functional and traditional resistance training improved muscular fitness outcomes in young men after 6 weeks (Zuo et al., 2022) and elderly men and women after 11 weeks (Lohne-Seiler et al., 2013) with minimal to no between group differences noted. Interestingly, our findings differed from these previous results with the THRESH group having significantly greater outcomes in both muscular fitness measurements compared to the STND group. These findings are similar to previous results using the same methodology (Dalleck et al., 2016) and may be due in part to the individualized nature of functional training and improvement in movement patterns (Stenger, 2018). Overall, these muscular fitness outcomes carry important clinical and CVD prevention meaningfulness. Across the past decade low muscular fitness has gained considerable attention as an independent and powerful predictor of CVD risk and premature mortality. For instance, Magnussen and colleagues (2012) reported that muscular power was inversely related to prevalence of clustered CVD risk. And more recently, greater levels of both upper- and lower-body muscular strength have been associated with lower risk of mortality (García-Hermoso et al., 2018).

Limitations

There are a few limitations that warrant further discussion. First, the research design included experimental groups with differing CRF and resistance exercise prescriptions to mimic a commonly implemented standardized-based program versus a threshold/personalized approach (Garber et al., 2011; American Council on Exercise, 2020; Liguori and American College of Sports Medicine, 2021) and thus prioritize ecological validity. The influence of CRF prescription on muscular fitness outcomes or the resistance exercise prescription on specific CRF outcomes was not directly analyzed and cannot be evaluated in the current study. While it is speculated there is limited impact on CRF adaptations from the resistance exercise protocols, these outcomes should be explored in future work. Second, repeated testing was not included at baseline and post-program in the study design, and we were unable to quantify measurement error and day-to-day variability in variables. The use of repeat testing has been recommended for investigations aiming to evaluate individual-based outcomes rather than group changes. Instead, we estimated the proportion of likely responders with the use of an AUC calculation above the MCID as a previously recommended approach (Atkinson et al., 2019). Lastly, participants were instructed to maintain the eating habits and typical physical activity, but these variables were not measured nor directly controlled, and we cannot rule out influences of these factors.

Conclusion

In the present study, both exercise groups significantly improved CRF as measured by VO_2max following 13-weeks of exercise prescription with progressive increases in exercise intensity. However, the magnitude of these changes were significantly different from each other with the THRESH group having a change of 4.85 ± 1.86 $mL \cdot kg^{-1} \cdot min^{-1}$ compared to 2.13 ± 1.68 $mL \cdot kg^{-1} \cdot min^{-1}$ in the STND group from pre- to post-program. Furthermore, the estimated proportion of likely responders was considerably higher in the THRESH group compared to the STND group. Moreover, the THRESH group experienced more favorable and significant adaptations in various measures of muscular fitness and cardiometabolic health. In many instances, some form of exercise is better than no exercise to enhance and improve health-related outcomes. However, in keeping with evidence-based practice (Amonette, et al., 2010), exercise professionals and other practitioners should take into consideration each individual and prescribe personalized exercise that is research substantiated and increases the probability that a meaningful physiological change will be experienced (Bonafiglia et al., 2022).

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Key points

- The use of ventilatory thresholds as anchors for cardiorespiratory fitness exercise combined with functional muscular fitness training yielded more favorable health-related outcomes compared to other groups.
- The proportion of participants estimated as likely responders was considerably greater in the personalized group compared to the other groups.
- Both personalized and standardized exercise programs had more favorable outcomes compared to the control group – exercise is better than no exercise for improving various health-related outcomes.

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