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ORIGINAL RESEARCH

DOES A PERSONALISED EXERCISE PRESCRIPTION ENHANCE TRAINING EFFICACY AND LIMIT TRAINING UNRESPONSIVENESS? A RANDOMISED CONTROLLED TRIAL

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ABSTRACT

Purpose: Evidence suggests considerable heterogeneity in exercise-induced changes in cardiorespiratory fitness and common cardiometabolic risk factors, with some individuals even experiencing adverse responses when exposed to regular exercise training. The purpose of this study was to compare the effectiveness of two exercise training programs for improving fitness and cardiometabolic health.

Methods: Sedentary men and women (n=46) performed 60-75 min/day, 3 days/wk for 13wk according to one of two exercise training regimens: 1) a standardised program, or 2) an individualised program (ACE IFT).

Results: Maximal oxygen uptake (VO_2max), body composition, systolic blood pressure (BP), and muscular fitness increased more favourably ($p<0.05$) in the ACE IFT treatment group. In the standardised treatment group 64.3% (9/14) of individuals experienced a favourable change in relative VO_2max ($\Delta > +5.9\%$) and were categorised as responders. Alternatively, exercise training in the ACE IFT treatment group elicited a positive improvement in relative VO_2max ($\Delta > +5.9\%$) in 100% (14/14) of the individuals. Furthermore, the incidence of anthropometric, cardiometabolic,and muscular fitness responders to exercise training were overall more favourable ($p<0.05$) in the ACE IFT treatment group: waist circumference (92.9% vs. 78.6%), percent body fat (100.0% vs. 78.6%), systolic BP (100.0%vs. 42.9%), HDL cholesterol (100.0% vs 50%), blood glucose (92.9% vs.42.9%), bench press 5-RM (100.0% vs 64.3%), and leg press 5-RM (100.0% vs 64.3%).

Conclusions: The major findings from the present study were as follows: 1) an individualised exercise prescription elicited significantly ($p<0.05$) greater improvements in VO_2max, muscular fitness, and key cardiometabolic risk factors when compared to a standardised exercise prescription, and 2) an individualised exercise prescription increased training responsiveness when compared to a standardised exercise training program as evidenced by the significantly reduced ($p<0.05$) incidence of exercise training non-responders in the ACE IFT treatment group. These novel findings are encouraging and underscore the importance of a personalised exercise prescription to enhance training efficacy and limit training unresponsiveness.

Key words: Cardiores piratory fitness, Muscular fitness, Cardiovascular Disease, Exercise training, Primary prevention, VO_2max

INTRODUCTION

It is well accepted that regular exercise training confers positive effects on cardiorespiratory fitness (i.e., VO_2max) and cardiometabolic risk factors (e.g., elevated triglycerides and impaired fasting blood glucose) related to cardiovascular morbidity and mortality[1]. Nonetheless, it has also been highlighted that considerable heterogeneity exists with respect to the individual VO_2max improvement (-33.2% to +58%) in response to chronic exercise training[2-5]. Furthermore, emerging evidence also suggests considerable individual variability in exercise-induced changes in common cardiometabolic risk factors (e.g., blood pressure and lipid parameters), with some individuals even experiencing adverse responses (i.e., a response in an unfavorable direction) when exposed to regular exercise training[6-8]. Indeed, Bouchard and colleagues[7] reported that adverse responses in individual cardiometabolic risk factors ranged from 8 to 13% in sedentary adults undergoing 4 to 6 months of aerobic exercise training.

Recently, it has been identified that a more individualised and evidence-based approach to the exercise prescription is needed to enhance training efficacy and limit training unresponsiveness[9]. One such strategy that supports an individualised approach to the exercise prescription is the Integrated Fitness Training (IFT) model developed by the American Council on Exercise (ACE). The ACE IFT model is a systematic approach to designing programs based on the unique abilities, needs and goals of each individual[10]. The ACE IFT model incorporates components of cardiorespiratory, functional, and resistance training. However, scientific evidence supporting the effectiveness of the ACE IFT model is lacking. Therefore, the purpose of this study was to compare the effectiveness of two training programs for improving fitness and cardiometabolic health: the ACE IFT model versus a standardised exercise program. It was hypothesised that given the individualised approach, the ACE IFT model would elicit more positive responders to the intervention. In contrast, the standardised exercise training program would result in more non-responders.

METHODS

Participants

Forty-six nonsmoking men and women (44 to 83 yrs) were recruited from the faculty population of a local university, as well as the surrounding community, via advertisement through the university website, local community newspaper, and word-of-mouth. Participants were eligible for inclusion into the study if they were low-to-moderate risk as defined by the American College of Sports Medicine (ACSM) and sedentary[11]. Participants were considered sedentary if they reported not participating in at least 30 min of moderate intensity physical activity on at least three days of the week for at least three months[11]. Participants were also eligible for inclusion into the study if they verbally agreed to continue previous dietary habits and not perform additional exercise beyond that required for the present study. Exclusionary criteria included evidence of cardiovascular, pulmonary, and/or metabolic disease as determined by medical history questionnaire. This study was approved (HRC2016-01-01R1) by the Human Research Committee at Western State Colorado University. Each participant signed an informed consent form prior to participation.

Baseline and post-program experimental testing procedures

Measurements of all outcome variables were obtained both before and after the exercise training intervention. All measurements were obtained across two nonconsecutive days (testing day #1 and testing day #2) by following standardised procedures we have employed previously in exercise training interventions performed in our laboratory[12]. Further detail for each of these measurement are provided below. On testing day #1 prior to fasting blood lipid and blood glucose measurement participants refrained from all food and drink other than water for 12 hours. On testing days #1 and #2 participants were also instructed to refrain from strenuous exertion 12 hours prior to testing. All post-program testing took place within 1 to 4 days of the last exercise training session.

Resting Heart Rate and Blood Pressure measurement

The procedures for assessment of resting heart rate and blood pressure (BP) outlined elsewhere were followed[11]. Briefly, participants were seated quietly for 5 minutes in a chair with a back support with feet on the floor and arm supported at heart level. Resting heart rate was obtained via manual palpation of radial artery in the left wrist and recording the number of beats for 60 seconds. Systolic and diastolic BP were measured using a sphygmomanometer in duplicate and separated by 1-minute. The mean of the two measurements was reported for baseline and post-program values.

Anthropometric measurements

Participants were weighed to the nearest 0.1 kg on a medical grade scale and measured for height to the nearest 0.5 cm using a stadiometer. Percent body fat was determined via skinfolds[11]. Skinfold thickness was measured to the nearest ± 0.5 mm using a Lange caliper (Cambridge Scientific Industries, Columbia, MD). All measurements were taken on the right side of the body using standardised anatomical sites (three-site) for men and women. These measurements were performed until two were within 10% of each other. Waist circumference measurements were obtained using a cloth tape measure with a spring loaded-handle (Creative Health Products, Ann Arbor, MI). A horizontal measurement was taken at the narrowest point of the torso (below the xiphoid process and above the umbilicus). These measurements were taken until two were within 0.5 mm of each other.

Fasting blood lipid and blood glucose measurement

All fasting lipid and blood glucose analyses were collected at room temperature. Participants' hands were washed with soap and rinsed thoroughly with water, then cleaned with alcohol swabs and allowed to dry. Skin was punctured using lancets and a fingerstick sample was collected into heparin-coated 40 µl capillary tube. Blood was allowed to flow freely from the fingerstick into the capillary tube without milking of the finger. Samples were then dispensed immediately onto commercially available test cassettes for analysis in a Cholestech LDX System (Alere Inc., Waltham, MA) according to strict standardised operating procedures. The LDX Cholestech measured total cholesterol, high density lipoprotein (HDL) cholesterol, low density lipoprotein (LDL) cholesterol, triglycerides, and blood glucose in fingerstick blood. A daily optics check was performed on the LDX Cholestech analyser used for the study. Independent studies have provided data to indicate that the Cholestech LDX system has excellent reproducibility with standard clinical laboratory measurement of plasma lipids and lipoproteins[13-14] and meets the National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP) criteria for accuracy and reproducibility[15].

Functional and muscular fitness assessments

The procedures for assessment of functional and muscular fitness assessment outlined elsewhere were followed[10]. Functional assessments was quantified using the stork-stand balance test to assess static balance. Participants were asked to raise one foot off the ground and bring the foot to lightly touch the inside of the stance leg, just below the knee. This measurement was repeated on the opposite leg. Timing was stopped if any of the following occurred: stance of support foot moved in any direction, any part of elevated leg lost contact with the stance leg, or the participant lost balance. Participants performed five-repetition maximum (5-RM) testing for the bench press and leg press exercises to assess muscular fitness. The following protocol was used for 5-RM testing:

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 minute 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 minute rest period
3. First 5-RM attempt at weight of 2.5-20kg greater then warm up
   - If first 5-RM lift was deemed successful by the researcher (appropriate lifting form) weight was increased until maximum weight participant can lift was established with 3

minutes between each attempt.
- If first 5-RM lift deemed unsuccessful by the researcher, weight was decreased until participant successfully lifted the heaviest weight possible

There were 3 minutes rest between 5-RM attempts and a maximum of 3 x 5-RM attempts. There were 5 minutes of rest between the 5-RM testing of each resistance exercise.

Maximal exercise testing

Participants completed a modified-Balke, pseudo-ramp graded exercise test on a motorised treadmill (Powerjog GX200, Maine, USA). Participants walked or jogged at a self-selected pace. Treadmill incline was increased by 1% every minute until the participant reached volitional fatigue. Participant HR was continuously recorded during the GXT via 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 analyser (Parvo Medics TrueOne 2.0, Salt Lake City, UT, USA). Before each exercise test, the metabolic analyser was calibrated with gases of known concentrations (14.01 ± 0.07% O_2, 6.00 ± 0.03% CO_2) and with room air (20.93%O_2 and 0.03% CO_2) as per the instruction manual. Volume calibration of the pneumotachometer was done via a 3-Litre calibration syringe system (Hans-Rudolph, Kansas City, MO, USA). The last 15s of the GXT were averaged – this was considered the final data point. The closest neighbouring data point was calculated by averaging the data collected 15s immediately before the last 15s of the test. The mean of the two processed data points represented VO_2max. Maximal HR was considered to be the highest recorded HR in beats per minute (bpm) during the GXT. Participant heart rate reserve (HRR) was determined by taking the difference between maximal HR and resting HR.

Determination of ventilatory thresholds

Determination of both the first ventilatory threshold (VT1) and second ventilatory threshold (VT2) were made by visual inspection of graphs of time plotted against each relevant respiratory variable (according to 15s 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[16]. All assessments were done by two experienced exercise physiologists. In the event of conflicting results, the original assessments were reevaluated and collectively a consensus was agreed upon.

Randomisation and exercise intervention

After recruitment, participants were randomised 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 (Figure 1). 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 randomised to the exercise training groups performed 13wk of exercise training according to one of two programs: 1) the ACE IFT model[10], or 2) a standardised program according to current American College of Sports Medicine (ACSM) guidelines[11]. Each exercise training group performed a similar frequency and duration of exercise training. Overall, the exercise prescriptions for both group were intended to satisfy the consensus recommendation of 150 min/wk[1].

Cardiorespiratory fitness exercise prescription

Cardiorespiratory fitness training was performed on various aerobic modalities: arm, cycle, and rowing ergometers; elliptical crosstrainer, and treadmill. The exercise intensity method for the cardiorespiratory fitness exercise prescription differed between treatment groups. The standardised training group was prescribed exercise intensity according to a percentage of HRR. Conversely, the ACE IFT model training group was prescribed exercise intensity according to ventilatory threshold. In both exercise training groups a target heart rate (HR) coinciding with either the prescribed HRR or prescribed VT

(Figure 1) was used to establish a specific exercise training intensity for each exercise session. In the ACE IFT model group target HR for each training zone (Figure 1) 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 just above VT2

Exercise training was progressed according to recommendations made elsewhere by the ACE[10] and ACSM[11]. Polar HR monitors (Polar Electro Inc., Woodbury, NY, USA) were used to monitor HR during all exercise sessions. Researchers adjusted workloads on aerobic modalities accordingly during each exercise session to ensure actual HR responses aligned with target HR. All cardiorespiratory fitness exercise prescription details for each training group over the course of the 13wk training period are presented in Figure 1.

Resistance and functional exercise prescription

Resistance and functional training commenced during week 4 of the overall study for both treatment groups and was subsequently completed 3 days a week for the remainder of the intervention. All sessions were supervised by researchers who closely monitored adherence to the prescribed program,

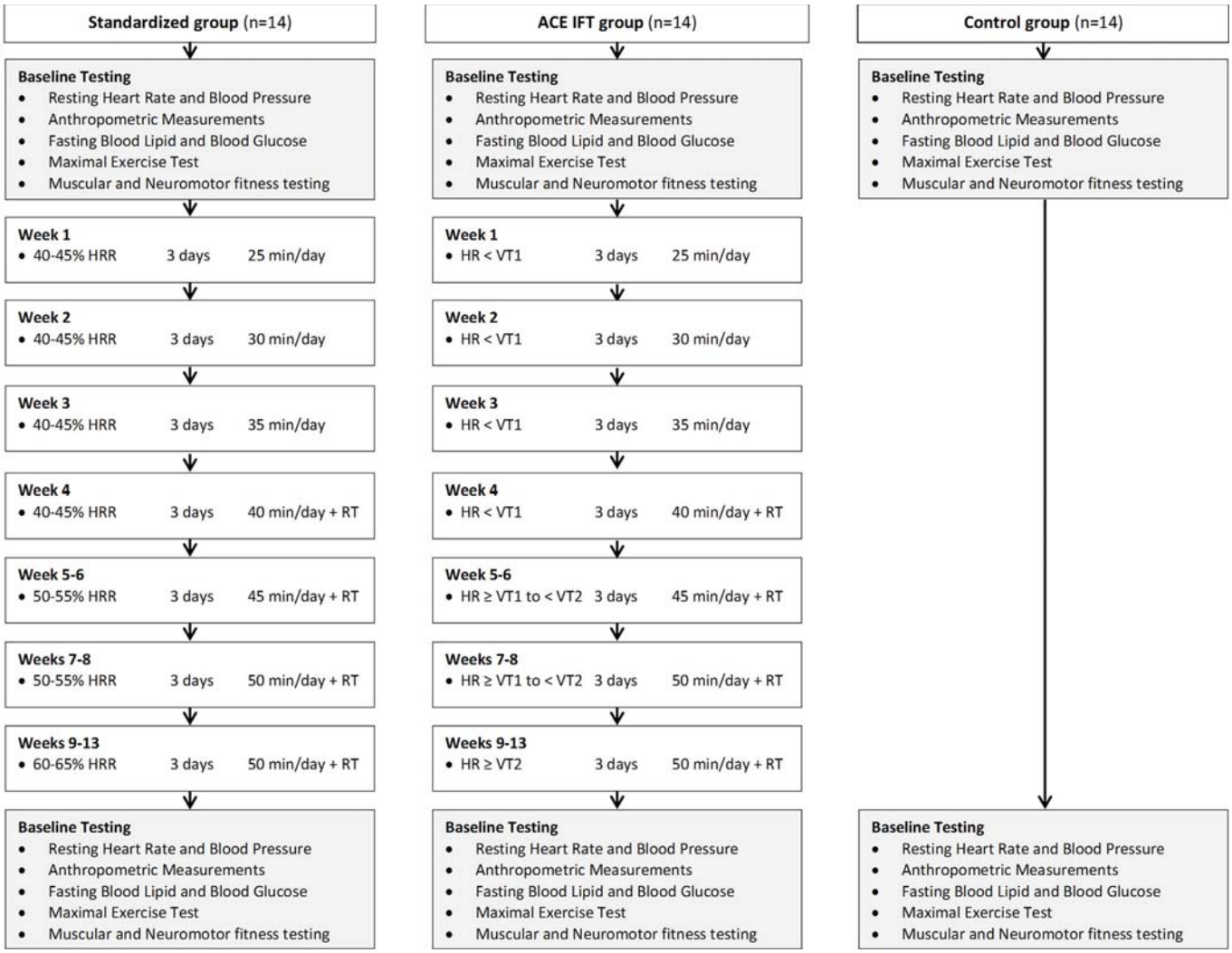

Figure 1. Flow chart of experimental procedures and exercise prescription for each of the two exercise training treatment groups and the non-exercise control group after randomisation. ACE IFT, American Council on Exercise Integrated Fitness Training, HR, heart rate; HRR, heart rate reserve; RT, resistance training; VT1, first ventilatory threshold; VT2, second ventilatory threshold.

ensured proper technique for each exercise, and provided specific information on progression. The details of the resistance and functional exercise prescription are outlined below.

Standardised group

The resistance training program for the standardised treatment group was designed according ACSM guidelines[11] and consisted of single and multi-joint exercises completed using machine modalities. The following traditional exercises were performed: bench press, shoulder press, lateral pulldown, seated row, bicep curl, tricep pushdown, seated leg press, seated leg extension, prone lying leg curl, and seated back extension/flexion. Two sets of 12 repetitions at a moderate intensity of 5–6 on the modified Borg rating of perceived exertion (RPE) scale[17] were completed for each lift and rated according to guidelines published by Sweet et al[18]. Resistance was progressed every 2 weeks by ~3-5% of total weight lifted for the upper body and ~6-10% for lower-body exercises so that the session RPE of 5–6 was maintained across the training program.

ACE IFT group

The resistance training program for the ACE IFT treatment group was designed according to ACE guidelines[10] 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 limited to a specific arc. The following exercises were performed in the ACE IFT treatment 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 was progressed by 5% 5-RM increments every 2 weeks. For exercises that did not include a 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.

Statistical analyses

All analyses were performed using SPSS Version 22.0 (Chicago, IL, USA) and GraphPad Prism 6.0. (San Diego, CA, USA). Sample size was projected with change in VO_2max as the main outcome variable. The means and standard deviation (SD) of a previous study[19] were examined and the effect size of this study was calculated. Assuming that a power of 0.90 was needed and the calculated effect size for change in VO_2max was 0.8, it was determined that approximately 12 participants would be needed for each of the three groups[20]. Further, we assumed there would be an approximate 20% dropout rate based on findings from one of our previous exercise training studies[2]. Accordingly, we recruited and randomised an additional three participants to each of the exercise training groups and control group to account for potential attrition.

Measures of centrality and spread are presented as mean ± SD. All baseline-dependent variables were compared using general linear model (GLM) ANOVA and, where appropriate, Tukey post hoc tests. Within-group comparisons were made using paired t-tests. All between-group 13wk changes were analysed using GLM-ANOVA and, where appropriate, Tukey post hoc tests. The assumption of normality was tested by examining normal plots of the residuals in ANOVA models. Residuals were regarded as normally distributed if Shapiro-Wilk tests were not significant.[19]

Delta values (Δ) were calculated (post-program minus baseline value divided by baseline value) for percent change in relative VO_2max (%) and participants were categorised as: '1' = responders (% $\Delta > +5.9\%$) or '0' = non-responders ($\Delta \leq +5.9\%$) to exercise training using a day-to-day variability, within subject coefficient of variation (CV) criterion applied previously in the literature[5,21]. Delta values (Δ) were calculated (post-program minus baseline values) for all other outcomes and participants were categorised as: '1' = responders ($\Delta > 0$) or '0' = non-responders ($\Delta \leq 0$) to exercise training. Chi-square (χ^2) tests were subsequently used to analyse the incidence of responders and non-responders to exercise training separated by treatment group (i.e., standardised and ACE IFT model) between baseline and post-

Table 1. Physical and physiological characteristics at baseline and 13wk for control, Standardised, and ACE IFT groups. (Values are mean ± SD).

Parameter	Control group (n=14; women = 8, men = 6)		Standardised group (n=14; women = 6, men = 8)		ACE IFT group (n=14; women = 6, men = 8)	
	Baseline	13wk	Baseline	13wk	Baseline	13wk
Age (yr)	62.4 ± 6.8	____	67.4 ± 8.3	____	64.9 ± 10.0	____
Height (cm)	167.2 ± 9.5	____	167.0 ± 8.1	____	168.9 ± 10.7	____
Body mass (kg)	76.2 ± 8.3	76.4 ± 7.7	82.3 ± 16.8	81.7 ± 17.2	84.0 ± 19.8	83.2 ± 18.8
Waist circumference (cm)	89.2 ± 7.7	89.4 ± 7.3	95.6 ± 14.0	93.3 ± 14.6	92.4 ± 11.2	89.1 ± 10.6*†
Body fat (%)	30.5 ± 4.2	31.7 ± 4.2*	35.0 ± 6.0	33.6 ± 4.8†	35.1 ± 6.4	31.9 ± 6.5*‡
Fat free mass (kg)	53.0 ± 6.2	52.2 ± 5.8*	53.5 ± 11.7	54.3 ± 12.0†	54.5 ± 12.2	56.7 ± 11.1*‡
Resting HR ($b \cdot min^{-1}$)	66.8 ± 12.3	66.0 ± 8.4	75.3 ± 4.3	75.4 ± 6.9	71.4 ± 10.7	68.8 ± 14.7
Maximal HR ($b \cdot min^{-1}$)	156.5 ± 10.4	155.0 ± 7.9	148.7 ± 9.6	150.4 ± 8.6	152.7 ± 11.0	154.9 ± 9.6*
VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	25.1 ± 4.7	24.7 ± 4.4	22.2 ± 11.0	24.0 ± 10.8*†	25.5 ± 6.3	29.1 ± 6.8*‡
Systolic BP (mmHg)	117.4 ± 9.8	120.5 ± 9.3*	121.6 ± 10.3	121.7 ± 12.4	125.4 ± 6.2	118.3 ± 5.2*‡
Diastolic BP (mmHg)	77.6 ± 8.7	81.3 ± 5.2	77.3 ± 7.9	77.4 ± 8.0	79.4 ± 5.5	74.9 ± 6.2*‡
Total cholesterol ($mmol \cdot L^{-1}$)	5.17 ± 0.96	5.18 ± 0.79	5.03 ± 1.18	5.32 ± 1.44	5.08 ± 1.31	5.12 ± 1.25
HDL cholesterol ($mmol \cdot L^{-1}$)	1.24 ± 0.59	1.21 ± 0.51	1.37 ± 0.49	1.41 ± 0.47	1.29 ± 0.52	1.42 ± 0.52*†
LDL cholesterol ($mmolg \cdot L^{-1}$)	3.05 ± 0.84	3.07 ± 0.73	3.01 ± 0.64	3.10 ± 0.52	2.78 ± 0.72	2.76 ± 0.77
Triglycerides ($mmol \cdot L^{-1}$)	1.41 ± 0.41	1.63 ± 0.54*	1.22 ± 0.66	1.12 ± 0.62*†	1.21 ± 0.46	1.09 ± 0.48*†
Blood Glucose ($mmol \cdot L^{-1}$)	4.97 ± 0.28	5.03 ± 0.41	5.07 ± 0.52	5.10 ± 0.59	5.20 ± 0.44	5.00 ± 0.41*†
Right leg Stork-stand (sec)	37.4 ± 29.7	35.4 ± 29.6	31.9 ± 28.4	37.4 ± 32.0*	26.9 ± 25.0	44.6 ± 35.3*‡
Left leg Stork-stand (sec)	29.1 ± 20.6	26.3 ± 19.3*	24.7 ± 20.0	31.1 ± 23.8*†	26.3 ± 23.9	41.7 ± 28.5*‡
Bench press 5-RM (kg)	21.9 ± 17.6	21.6 ± 17.7	25.3 ± 17.4	28.6 ± 20.7*†	25.9 ± 14.7	32.0 ± 16.1*‡
Leg press 5-RM (kg)	53.3 ± 48.9	53.4 ± 48.0	51.6 ± 32.0	64.3 ± 37.1*†	67.3 ± 24.4	91.3 ± 31.8*‡

** Within-group change is significantly different from baseline, p<0.05; † Change from baseline is significantly different than control group, p<0.05; ‡ Change from baseline is significantly different than control and Standardised groups, p<0.05.*

program. The probability of making a Type I error was set at $p<0.05$ for all statistical analyses.

RESULTS

All analyses and data presented in the results are for those participants who completed the investigation. At baseline, treatment (standardised and ACE IFT) and non-exercise control groups did not differ significantly in physical or physiological characteristics. The physical and physiological characteristics for participants are shown in Table 1.

The exercise prescription in both treatment groups was well tolerated for the 28 of 32 participants who completed the study. Four participants were unable to complete the study for the following reasons: personal reasons (n=2), illness (n=1), and out-of-town move (n=1). Dropout was similar in both treatment groups. Overall, there was excellent adherence to the total number of prescribed training sessions: standardised group – mean, 93.1% (range, 74.3-100%) and ACE IFT group – mean, 90.7% (range, 76.9-100%). Additionally, adherence to the prescribed cardiorespiratory exercise intensity for

Table 2. Prescribed and actual exercise intensity for cardiorespiratory exercise for Standardised and ACE IFT treatment groups throughout the 13wk exercise intervention.

	Standardised Group (n=14)			ACE IFT Group (n=14)		
Week	Prescribed intensity	THR	Actual HR	Prescribed intensity	THR	Actual HR
1	40-45% HRR	105 ± 12 to 108 ± 12	107 ± 11	HR < VT1	104 ± 10 to 113 ± 10	109 ± 11
2	40-45% HRR	105 ± 12 to 108 ± 12	108 ± 12	HR < VT1	104 ± 10 to 113 ± 10	111 ± 9
3	40-45% HRR	105 ± 12 to 108 ± 12	107 ± 9	HR < VT1	104 ± 10 to 113 ± 10	112 ± 8
4	40-45% HRR	105 ± 12 to 108 ± 12	108 ± 10	HR < VT1	104 ± 10 to 113 ± 10	112 ± 8
5-6	50-55% HRR	112 ± 13 to 116 ± 14	113 ± 12	HR ≥ VT1 to < VT2	114 ± 11 to 123 ± 12	118 ± 10
7-8	50-55% HRR	112 ± 14 to 116 ± 15	115 ± 11	HR ≥ VT1 to < VT2	114 ± 11 to 123 ± 12	119 ± 11
9-13	60-65% HRR	118 ± 14 to 121 ± 14	120 ± 12	HR ≥ VT2	124 ± 12 to 132 ± 11	127 ± 10

Values are mean ± SD. HR, heart rate; HRR, heart rate reserve; THR, target heart rate; VT1, first ventilatory threshold; VT2, second ventilatory threshold.

both treatment groups throughout the duration of the intervention was excellent (Table 2).

After 13wk, changes in body mass, resting HR, total cholesterol, and LDL cholesterol were not significantly different ($p>0.05$) in either the standardised or ACE IFT treatment groups when compared with the control group. In contrast, changes from baseline to 13wk in VO_2max, body fat percentage, fat free mass, triglycerides, left leg Stork-stand, bench press 5-RM, and leg press 5-RM were significantly more desirable ($p<0.05$) in the standardised treatment group when compared with the control group. Likewise, changes from baseline to 13wk in waist circumference, HDL cholesterol, triglycerides, and blood glucose were significantly more desirable ($p<0.05$) in the ACE IFT treatment group relative to the control group. Additionally, changes in body fat percentage, fat free mass, VO_2max, systolic and diastolic BP, right and left leg Stork-stand, bench press 5-RM, and leg press 5-RM were significantly more favorable ($p<0.05$) in the ACE IFT treatment group when compared to the standardised treatment group and control group. All between-group and within-group changes from baseline to 13wk are presented in Table 1.

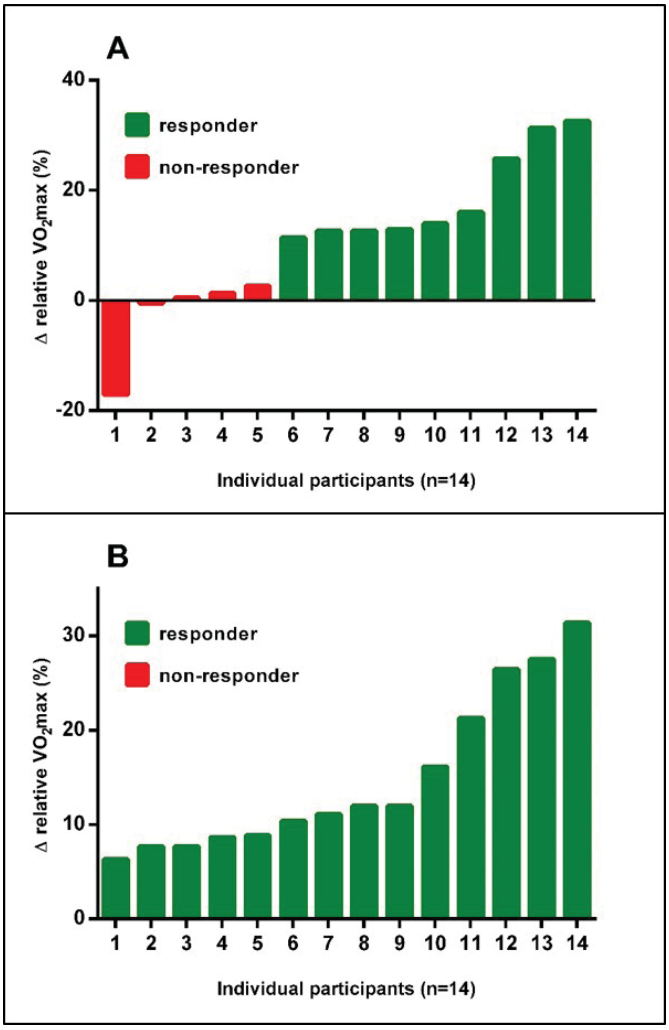

Figure 2. Individual variability in relative VO_2max response (% change) to exercise training in the Standardised (A) and ACE IFT (B) treatment groups.

Incidence of VO_2max non-responders and responders

The incidence of VO_2max responders and non-responders to exercise training in both the standardised and ACE IFT treatment groups are shown in Figure 2. In the standardised treatment group 64.3% (9/14) of individuals experienced a favorable change in VO_2max ($\Delta > +5.9\%$) and were categorised as responders (Figure 2A). Alternatively, 35.7% (5/14) of individuals in the standardised treatment group experienced an undesirable change in VO_2max ($\Delta \leq +5.9\%$) and were categorised as non-responders to exercise training (Figure 2A). There were no significant differences ($p<0.05$) between treatment groups in several potential influencing factors of responder/non-responder, including age, baseline VO_2max, exercise adherence, and sex. In the ACE IFT treatment group the incidence of individuals who experienced a favorable change in VO_2max was significantly ($p<0.05$) greater when compared to the standardised treatment group. Indeed, exercise training in the ACE IFT treatment group elicited a positive improvement in VO_2max ($\Delta > +5.9\%$) in 100% (14/14) of the individuals (Figure 2B).

Incidence of cardiometabolic non-responders and responders

The incidence of cardiometabolic responders ($\Delta > 0$) to exercise training in the standardised treatment group were: systolic BP (42.9%), HDL cholesterol (50.0%), triglycerides (85.7%), and blood glucose (42.9%). In contrast, the incidence of cardiometabolic responders to exercise training were overall more favorable in the ACE IFT treatment group when compared to the standardised group: systolic BP (100.0%, $p<0.05$), HDL cholesterol (100.0%, $p<0.05$), triglycerides (85.7%, $p>0.05$), and blood glucose (92.9%, $p<0.05$). There were no significant differences ($p<0.05$) in several potential influencing factors of responder/non-responder, including age, baseline cardiometabolic risk factor value, exercise adherence, and sex.

Incidence of anthropometric non-responders and responders

The incidence of anthropometric responders ($\Delta > 0$) to exercise training in the standardised treatment group were: waist circumference (78.6%) and percent body fat (78.6%). In contrast, the incidence of anthropometric responders to exercise training were significantly ($p<0.05$) greater in the ACE IFT treatment group when compared to the standardised group: waist circumference (92.9%) and percent body fat (100.0%). There were no significant differences ($p<0.05$) in several potential influencing factors of responder/non-responder, including age, baseline anthropometric value, exercise adherence, and sex.

Incidence of muscular and neuromotor fitness non-responders and responders

The incidence of muscular and neuromotor fitness responders ($\Delta > 0$) to exercise training in the standardised treatment group were: right leg Stork-stand (78.6%), left leg Stork-stand (85.7%), bench press 5-RM (64.3%), and leg press 5-RM (64.3%). In contrast, the incidence of muscular and neuromotor fitness responders to exercise training were overall more favorable in the ACE IFT treatment group when compared to the standardised group: right leg Stork-stand (100.0%, $p<0.05$), left leg Stork-stand (92.9%, $p>0.05$), bench press 5-RM (100.0%, $p<0.05$), and leg press 5-RM (100.0%, $p<0.05$). There were no significant differences ($p<0.05$) in several potential influencing factors of responder/non-responder, including age, baseline muscular and neuromotor fitness value, exercise adherence, and sex.

DISCUSSION

The major findings from the present study were as follows: 1) an individualised exercise prescription elicited significantly ($p<0.05$) greater improvements in VO_2max, muscular fitness, and key cardiometabolic risk factors when compared to a standardised exercise prescription following 13wk of exercise training, and 2) an individualised exercise prescription increased training responsiveness when

compared to a standardised exercise training program as evidenced by the significantly reduced ($p<0.05$) incidence of exercise training non-responders in the ACE IFT treatment group. Therefore, these current results support both our research hypotheses and underscores the importance of a personalised exercise prescription to enhance training efficacy and limit training unresponsiveness. To our knowledge, this is the first prospective, randomised, controlled trial to compare individual variation in training responses following comprehensive, individualised exercise training versus standardised training.

Although not completely understood various factors are known to mediate the heterogeneity in training responses, including the parameters of the exercise training program itself. For instance, it has previously been demonstrated that one of the most important predictors of a positive VO_2max response to exercise training is a greater volume of exercise[22]. More recently, it has been suggested that the method of exercise intensity prescription may underpin the inter-individual variation in VO_2max response to exercise training[23]. The previous studies[3-4,24] that have reported widespread variability in the individual VO_2max response to exercise training have used one of several relative exercise intensity methods, including %HRmax, %HRR, or %VO_2max. However, it has been demonstrated that these "one size fits all" relative exercise intensity prescription methods elicit large inter-individual variation in the metabolic responses to exercise training[23,25]. On this premise, it has been suggested that the individual variation in metabolic response will subsequently lead to differences in the overall homeostatic stress from each training session which will ultimately result in heterogeneity in the exercise training response. Alternatively, it has been suggested that use of a threshold based method for establishing exercise intensity might better normalise the metabolic stimulus for individuals with varying fitness levels[10,26]. Findings from the present study support this paradigm. Indeed, it was demonstrated that a threshold based exercise intensity prescription, as employed in the ACE IFT treatment group, elicited significantly more desirable training adaptations in VO_2max, systolic blood pressure, and body composition. Moreover, a threshold based approach to exercise training elicited greater training responsiveness as evidenced by the significantly higher incidence of responders in the ACE IFT treatment group when compared to the standardised group. More favorable improvements in 5-RM bench press, 5-RM leg press, and both right/left leg Stork stand scores and a higher incidence of responders in all of these parameters were also observed in the ACE IFT treatment group when compared to the standardised group. To our knowledge, we are the first to show that a personalised resistance and neuromotor exercise prescription can enhance training efficacy and limit training unresponsiveness in these fitness domains. Given the various health problems linked to age-related declines in muscle strength and balance these novel findings have important clinical implications.

In the past few decades both low cardiorespiratory and muscular fitness have garnered considerable attention as independent and powerful predictors of cardiovascular disease (CVD) risk and premature mortality. For instance, it has been reported that increased muscular fitness is associated with a reduced risk of all-cause mortality[27]. Likewise, Williams[28] showed in a meta-analysis that there was a marked decrease in relative risk for CVD when individuals moved out of the lowest quartile of cardiorespiratory fitness. More recently Blair[29] estimated that low cardiorespiratory fitness accounted for more overall deaths when compared to deaths which could be attributed to traditional CVD risk factors, such as obesity, smoking, hypertension, high cholesterol, and diabetes. Accordingly, the changes in cardiorespiratory (i.e., VO_2max) and muscular fitness (i.e., 5-RM bench and leg press scores) in the ACE IFT treatment group from the current study have novel clinical and public health relevance, as a large number of adults fall into clinically-defined low cardiorespiratory and muscular fitness categories and therefore demonstrate increased CVD risk[30]. Importantly, exercise training in the ACE IFT treatment group elicited a positive improvement in VO_2max in 100% (14/14) of the individuals. Overall, VO_2max was improved on

average by 1.0 METs in the ACE IFT treatment group following 13wk of exercise training. These improvements likely have important long-term prevention implications as it has been previously reported that a 1 MET increase in VO_2max was associated with an 18% reduction in deaths due to CVD[31].

There are a few limitations to the present study that warrant further discussion. First, overall sample size in our study is lower than other major exercise training studies in the literature[19,22]. However, advantages of a smaller sample size were the ability to better supervise the exercise program and more closely interact with participants on a daily basis during exercise sessions[32]. In particular, the adherence to the prescribed exercise program was excellent for both exercise treatment groups. Second, while participants were instructed to maintain their regular dietary intake during the 13wk intervention, diet intake was not strictly controlled for in this study. Moreover, physical activity/sedentary behaviour outside of the training program and prescribed medications were not monitored, and thus may have influenced the current findings.

CONCLUSION

There is a wealth of previous research reporting that regular exercise training confers positive effects on fitness (cardiorespiratory and muscular) and numerous other cardiometabolic outcomes related to cardiovascular morbidity and mortality. Nonetheless, it has also been highlighted that considerable heterogeneity exists with respect to the individual responses to chronic exercise training. In the present study it was demonstrated that a personalised exercise prescription enhanced training efficacy and limited training unresponsiveness.

PRACTICAL APPLICATIONS

In the present study an individualised exercise prescription elicited significantly greater improvements in VO_2max, muscular fitness, and key cardiometabolic risk factors and significantly reduced the incidence of exercise training non-responders. The individualised exercise prescription consisted of a threshold based approach and % 5-RM method to establishing exercise intensity for cardiorespiratory and resistance exercise, respectively. In the event that direct determination of VT1 and VT2 are not available, practitioners can make use of the talk test to establish the appropriate and individualised exercise intensity for the cardiorespiratory fitness exercise prescription[33]. In summary, the novel findings from the present study are encouraging and provide important preliminary data for exercise physiologists, fitness professionals, and others who design exercise training programs in the adult/older adult populations.

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AUTHORS' CONTRIBUTIONS:

Conception and design of the experiment: LD, CB, RW. Performance of the experiment: LD, DH. Analyses of the data: LD, DH. Preparation of the manuscript: LD, DH, CB, RW. All authors read and approved the final manuscript.

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