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Changes in Fitness-Fatness Index following a Personalized, Community-Based Exercise Program in Physically Inactive Adults: A Randomised Controlled Trial

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ABSTRACT

International Journal of Exercise Science 15(4): 1418-1429, 2022. Fitness-fatness index (FFI) is used to identify those at high risk of developing type 2 diabetes and cardiovascular events. It is measured as the ratio between an individual's cardiorespiratory fitness (CRF) and waist-to-height ratio. Studies suggest that CRF and waist-to-height ratio are modifiable and can be improved by exercise. However, there is limited evidence surrounding a personalized approach to exercise prescription. This study investigated the impact of a 12-week personalized exercise program on FFI among sedentary individuals. It was hypothesized that the intervention would be effective in improving FFI in this cohort. One hundred and forty-two participants were randomized into two groups: i) personalised community-based intervention (n = 70); or ii) control (n = 72). Both groups underwent baseline anthropometric testing and a submaximal 'talk-test' to determine individual exercise intensities and baseline FFI. During the intervention, the control group underwent normal activities, whilst the treatment group received a 12-week personalised exercise program based on the American Council on Exercise (ACE) Integrated Fitness Training (IFT) guidelines. After 12-weeks, the treatment group demonstrated a significant increase in FFI (+13%), whilst the control group (-2%) showed a slight decrease (between-group difference, p = < 0.001). Both CRF (+12%) and waist-to-height (-2%) also showed significant favourable changes in the treatment group, with no change in the control group (between group difference, p = 0.01). These findings indicate that a personalised approach to exercise prescription using the ACE IFT guidelines are beneficial in reducing FFI. Consequently, FFI could be implemented within standardized approaches to exercise to help reduce the risk of developing chronic conditions.

KEY WORDS: Cardiorespiratory fitness, exercise prescription, metabolic syndrome

INTRODUCTION

Metabolic syndrome is defined as a cluster of metabolic abnormalities which has become prevalent due to an increase in obesity and sedentary behaviour worldwide (21). Furthermore, metabolic syndrome can increase the risk of developing type 2 diabetes mellitus (T2DM) and incident cardiovascular events. The prevalence of T2DM globally was 8.8% in 2015 and is expected to increase to 10.4% by 2040 (21). Previously, body mass index (BMI) has been used to predict the likelihood of cardiovascular disease and mortality risk, however, recent research has identified FFI (fitness-fatness index) as a more appropriate method of identifying those at high risk of developing T2DM and incident cardiovascular events (23). Sloan and colleagues (23) suggest that FFI can be calculated using an individual's maximal cardiorespiratory fitness divided by their waist-to-height ratio. This is supported by Edwards et al. (8) who found that for every 1-unit increase in FFI, there was a 9% decrease in all-cause mortality.

The Australian Institute of Health and Welfare (2) reported that in 2017-18, only 50% of adults met the physical activity guidelines. In Australia, a driving force of metabolic syndrome development has been increased sedentary behaviour, characterised by an energy expenditure of less than 1.5 METS in a seated, recline or supine posture (15), along with increased office work, TV, automobile use and lack of time (21). Cardiorespiratory fitness (CRF) and waist-to-height ratio are modifiable factors which can be improved following exercise training (10). CRF is defined as the ability of several physiological systems to efficiently supply and utilise oxygen at the muscular tissue level (16). Individuals with higher CRF compared to those with lower CRF are at a significantly reduced risk of all-cause mortality (16). This was further supported by Myers et al (17), who suggested that both men and women who ranked in the lowest percentile of maximum oxygen uptake (VO_2max) normative data had a 10.2-10.8 times greater risk of developing metabolic syndrome than those ranked in the highest VO_2max percentile. Possible mechanisms contributing to a higher CRF include improved blood lipid profiles, insulin sensitivity, body composition, blood pressure and inflammation (16).

Moreover, waist-to-height ratio is an indication of visceral adipose tissue (VAT) which is a hormonally active component of fat that is located within the abdominal cavity and can surround essential organs such as the intestines and the liver (29). Multiple studies have demonstrated a strong correlation between high levels of VAT and poor cardiometabolic health and all-cause mortality (25). A systematic review investigated the effects of exercise on VAT in overweight and obese adults and found an overall significant reduction in VAT after exercise for at least 12 weeks (2-5 times per week), especially following moderate to vigorous intensity aerobic exercise (27). Whilst the exact mechanisms by which exercise may act on VAT are largely unknown, one study proposed that exercise may mediate its effect on VAT through IL-6, which is a cytokine involved in energy metabolism including lipid metabolism (29).

Whilst community-based exercise programs have demonstrated a reduction of individual's cardiometabolic risk, there is limited evidence surrounding a personalized approach (6). Previous studies have shown that personalized approaches to exercise prescription using ventilatory thresholds elicits a greater training responsiveness (28). This includes favourable changes in VO_2max, muscular fitness and key cardiometabolic risk factors in those individuals who underwent personalized exercise prescription, compared to those who underwent a standardised exercise program (7). Therefore, the aim of this study was to evaluate the impact of a 12-week personalized exercise program on the changes in FFI among sedentary individuals. It was hypothesized that the 12-week personalized, community-based intervention compared to a standardised program would be more effective in improving FFI in this cohort.

METHODS

Participants

The randomised controlled trial recruited non-smoking men and women aged 18-83 years old. Participants were recruited from a local University and surrounding areas via web-based advertising, newsletters and word of mouth. Eligibility was determined as those participants who were classified as not currently physically active, defined as not currently completing at least 30 min of moderate-intensity physical activity on at least three days per week for a minimum of three months (7). This study was approved by the Human Research Committee at Western Colorado University. Participants were then included in the study after informed consent was provided. This research was carried out in accordance with the ethical standards of the International Journal of Exercise Science (18).

Protocol

The experimental flow chart outlining the study design is shown in Figure 1. Participants were randomized into either the treatment (personalised exercise program) or control groups using a computerized stratified minimization sequence to form even groups (N = 75). Those allocated into the control group were advised to continue their usual lifestyle habits. Moreover, those in the treatment group received a personalised exercise program. Participants attended testing visits which included anthropometric, muscular strength and cardiorespiratory fitness assessments.

Anthropometric Data Collection: Anthropometric measures included waist circumference and height to calculate waist-to-height ratio. Height was measured on a stadiometer to the nearest 0.5 cm. Waist circumference was measured using a cloth tape measure with a spring-loaded handle (Creative Health Products, MI). Measurement was taken horizontally at the narrowest point of the torso which lies above the umbilicus, but below the xiphoid process. Two measurements were recorded when they fell within 0.5 cm of each other. After testing, waist-to-height ratio was calculated by dividing waist circumference (cm), by height (cm).

Assessment of Muscular Strength: Muscular strength was determined via a 5-repetition maximum (RM) bench press and 5-RM leg press to determine baseline intensities for resistance training. The protocol used for both tests included a warm-up of 10 repetitions at 40-60% of the estimated 5-RM as professionally determined by the trainer. Following a 1-minute rest, participants would then perform 5 repetitions at 60-80% of the estimated 5-RM. This was repeated with 3 minutes rest in between each attempt until a maximal 5-RM was achieved with acceptable technique deemed by the trainer (7).

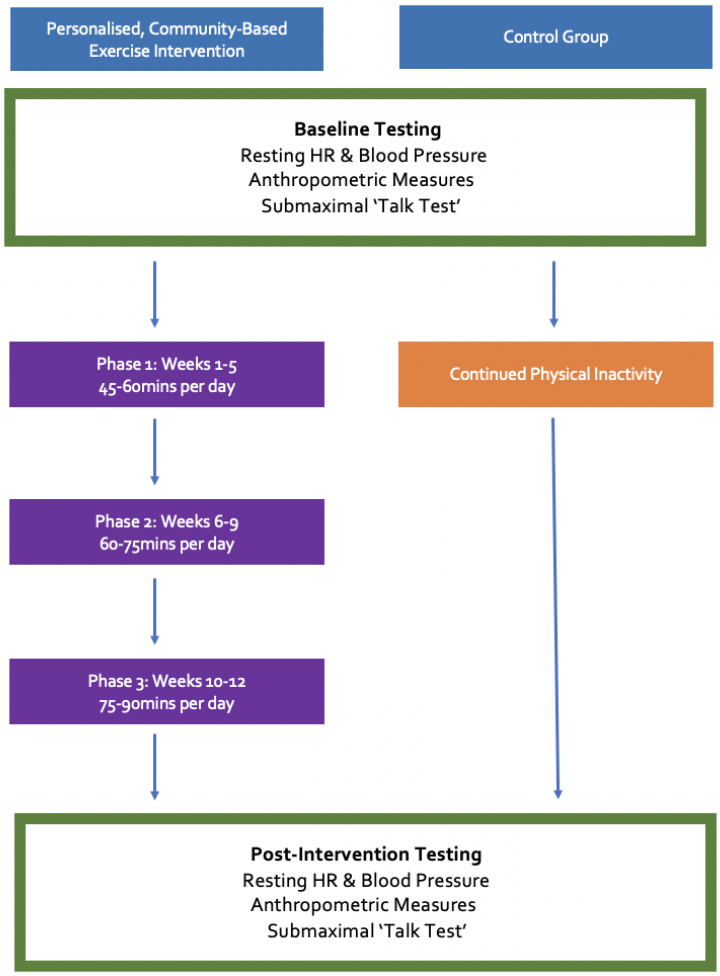

Figure 1. Experimental procedures for both groups, including the personalised, community-based exercise intervention and the control group.

Assessment of Cardiorespiratory Fitness: CRF was assessed via a submaximal 'talk-test' which has been established as a reliable tool for identifying ventilatory thresholds (VTs). VTs are markers of lactate accumulation within the blood and can be used to prescribe intensity during exercise (11). During an incremental exercise test, ventilation begins by rising linearly as the intensity increases, however, ventilation will break from this linear trend as exercise intensity increases (11). This is also known as the VT1 and is when the body increases ventilation to expel excess CO_2 which is used for buffering of lactate. VT2 is the second point and occurs when excess lactate starts to accumulate as buffering can no longer compensate (11). The talk test involves the participant performing an incremental exercise test on either a cycle ergometer or treadmill, depending on their training preference or orthopedic limitations. Before the test, blood pressure and heart rate were measured to obtain resting values. The test commenced with a warm-up of 3 minutes at a low intensity before the test was commenced with incremental stages with an objective to increase steady state heart rate (HR) at each stage by five beats per minute (bpm). At the end of each stage, heart rate and RPE was recorded, along with the individual having to recite a small pre-determined passage. VT1 is obtained when the participant can speak, but it becomes uncomfortable to challenging (20). In contrast, VT2 is established when the participant's ventilation becomes high and they are no longer able to speak the predetermined passage (20). VT2 is also referred to as the respiratory compensation threshold, therefore, beyond this point, the exercises will soon have to reduce their intensity to continue. This is mainly due to the fact that lactate levels begin to rise exponentially (20). At both VT1 and VT2, participant's heart rate was recorded to assist with the prescription of exercise.

Calculation of Fitness-Fatness Index: To determine FFI, estimated VO_2max was used from the submaximal cardiorespiratory test, along with waist-to-height ratio. Estimated VO_2max was calculated using the peak workload achieved in the submaximal talk test. From this workload, metabolic equivalent (MET) was calculated. A MET is defined as the resting metabolic rate or the amount of oxygen consumed at rest which is approximately 3.5 mL/kg/min (13). Consequently, any greater MET, means that the required workload is greater than the metabolism required at rest. Peak METS from this testing, could then be converted to estimate VO_2, by multiplying the MET by 3.5 mL/kg/min. FFI was then calculated by dividing cardiorespiratory fitness by waist to height ratio.

Individualized Exercise Prescription: For those allocated into the treatment group, each participant was allocated a team of health and fitness professionals and was assigned an undergraduate or graduate student from the local University who was their designated Personal Trainer. These student trainers were in direct supervision of trained Exercise Physiologists. This team then designed an individualized exercise program for each participant based on the American Council on Exercise (ACE) Integrated Fitness Training (IFT) guidelines (4).

For the cardiorespiratory training, various modalities including treadmills, cycle ergometers and arm ergometry were used. To establish the correct intensity of exercise, each participant was prescribed with an individualised intensity, based on their ventilatory thresholds VT1 and VT2 which were obtained during the baseline submaximal 'talk test'. From here, a target heart rate coinciding with the prescribed VT was given for all sessions which included both cardiorespiratory and resistance training. Heart rate was monitored during sessions using a heart rate monitor. Cardiorespiratory training was progressed as follows (7):

Week 1	HR < VT1	3 days	25 min/day
Week 2	HR < VT1	3 days	30 min/day
Week 3	HR < VT1	3 days	35 min/day
Week 4	HR < VT1	3 days	40 min/day
Weeks 5-6	HR ≥ VT1 to < VT2	3 days	45 min/day
Weeks 7-9	HR ≥ VT1 to < VT2	3 days	50 min/day
Weeks 10-12	HR ≥ VT2	3 days	50 min/day

The resistance training was designed using the ACE IFT guidelines. This included multi-joint exercises using both machine weights and free weights. The following exercises were included: stability ball circuit including glute bridges, crunches, Russian twists, lunges, woodchops, hay bailers, dumbbell squats, step-ups, and cable rows (4). Resistance exercises consisted of 2 sets of

12 repetitions with intensity commencing at 50% 5-RM. This intensity was progressed by 5% 5-RM every two weeks. For the intervention group, sessions were progressed in three phases as presented in Figure 1. Simultaneously, the control group were asked to continue their normal lifestyle habits.

Statistical Analysis
The primary outcome measure is the FFI change between groups. Secondary outcome measures include the change in waist-to-height ratio and VO_2max between groups. All data were analysed at the completion of the intervention using SPSS Version 27. Between group changes were analysed using a two-way ANCOVA test. Eta squared (η^2) group x time interaction effect sizes were calculated as between-group sum of squares divided by the total sum of squares and interpreted as follows: 'small-to-medium' effect (0.01 to 0.10); 'medium-to-large' effect (0.10 to 0.25); and 'large' effect (> 0.25) (26). The probability for making a Type I error was set at $p < 0.05$ for all statistical analyses.

RESULTS

The results from the participant demographics are presented in Table 1. These include the participants who were deemed eligible and completed the entirety of the study duration. At the commencement of the study, there were 75 participants allocated into each group. During the 12-weeks, some participants withdrew due to various reasons, leaving 72 participants in the control group and 70 participants in the treatment group for analysis. There were no adverse events reported during the 12-week intervention.

Table 1. Participant Demographics.

Variable	Treatment (*n* = 70)	Control (*n* = 72)
Age, years (Mean + SD)	47 ± 17	46 ± 13
Female, sex (%)	41	36
Weight (kg)	77 ± 2	75 ± 1
Systolic blood pressure (mmHg)	123 ± 2	119 ± 1
Diastolic blood pressure (mmHg)	80 ± 1	79 ± 1

Table 2 presents the results from participants before and after the 12-week intervention. Following the intervention, there was an increase in FFI among the treatment group of 13%, whilst the control group showed a small decrease in FFI (-2%), with a significant between group difference ($p < 0.001$). Moreover, increases were observed in participants VO_2max (+12%) within the treatment group, whilst the control group had no changes (between group difference, $p < 0.001$). Lastly, waist-to-height ratio showed a small change in the treatment group (-2%), whilst the control group had no change from pre to post intervention (between group difference, $p = 0.01$).

Table 2. Changes in cardiorespiratory fitness, waist to height ratio and fitness-fatness index following the 12-week exercise intervention.

Outcome Variables	Treatment Group		Control Group		Between Group Difference	Between Group Difference
	Baseline	*Post*	*Baseline*	*Post*	*P value*	*Effect size; η^2*
VO_2max (mL/kg/min)	31.38 ± 0.96	35.1 ± 0.97	28.96 ± 0.71	28.43 ± 0.68	< 0.001	0.602
waist-to-height ratio	0.50 ± 0.01	0.49 ± 0.01	0.49 ± 0.01	0.49 ± 0.01	0.01	0.054
FFI	66.14 ± 2.76	74.60 ± 2.86	59.90 ± 1.82	58.50 ± 1.70	< 0.001	0.625

DISCUSSION

The present study aimed to investigate the efficacy of a 12-week personalised, community-based exercise intervention on FFI among sedentary adults. These findings indicate that a personalized approach to exercise programming can promote a clinically significant increase in FFI of 13% after 12-weeks of training. Moreover, these changes were accompanied by a significant increase in CRF as measured by a submaximal exercise test. The results displayed a 12% increase in CRF at the conclusion of the intervention within the treatment group. Lastly, small but clinically significant reductions were seen in waist-to-height ratio after 12 weeks (-2%).

FFI which can be calculated using an individual's cardiorespiratory fitness, divided by their waist-to-height ratio is a means of identifying those at a higher risk of developing cardiometabolic diseases such as type 2 diabetes (25). The present study suggests that a 12-week personalized exercise program using the ACE IFT model guidelines could increase FFI by 13%. This finding could be deemed clinically significant as previous studies have shown that an increase in FFI by 1 unit is associated with a 9% decrease in all-cause mortality (8). Similarly, the study revealed that for the same 1-unit increase in FFI, there was a 11% decrease in cardiovascular related mortality. The data from this study offers a promising means of increasing FFI for individuals who may be at higher risk of cardiovascular related diseases. Based on these findings associated with the numerous benefits of FFI on decreasing mortality related events, it is feasible to suggest the use of a personalised approach to exercise prescription. This approach to exercise prescription may enhance FFI and reduce the incidence of multiple chronic diseases, along with premature mortality. A previous study also investigated the use of FFI as a predictor of mortality in cardiac patients including those with coronary artery disease, chronic heart failure of myocardial infarction (10). This study suggested that those patients with a higher FFI had a reduced rate of all-cause mortality (10). Consequently, this implies the usefulness of FFI, not only as a means of identifying those at-risk of developing chronic conditions, but as a health promotion tool to promote the benefits of personalized exercise training for those already suffering from the burden of disease.

In contrast, sedentary behaviour which is defined as behaviour characterised by an energy expenditure less than 1.5 METS in a seated, recline or supine posture, may be associated with several negative health consequences (15). Studies have demonstrated a link between sedentary behaviour and conditions such as obesity, insulin resistance and metabolic syndrome which can lead to higher cardiovascular risk and mortality (14). One study found that sedentary behaviour may be an important determinant of CRF levels, independent of physical activity, thus strategies designed to reduce sedentary behaviour are equally important to increasing physical activity levels in individuals (14). This was supported by Lavie et al (15), who suggested that the burden of sedentary behaviour appears to be a separate risk factor, with those spending more than 10 hours per day, having an 18% increased risk of cardiovascular disease, compared to those who sat less than 5 hours per day. Therefore, this is a factor which needs to be considered in terms of the current studies results as it was shown that the control group may have had a slight reduction in FFI over the 12 weeks. However, as sedentary behaviour was not measured directly, this change in FFI may have been influenced by several factors such as changes in lipid profile or vascular health which could influence either body composition or cardiorespiratory fitness (19).

An important component of FFI is CRF (8) which was shown to be increased by personalised, community-based exercise in the current study. CRF, as mentioned previously is the ability of several physiological systems to efficiently supply oxygen to the muscles, and the ability of these muscles to utilise this oxygen (16). Significant research has been conducted, exploring the benefits of CRF and its link to obesity and all-cause mortality. In the study by Tarp et al (24), they found a strong association between CRF, obesity and mortality, indicating that the highest mortality rates were found in those who were obese and unfit. Interestingly, those who were normal weight, but classified as unfit by their low CRF were at a higher risk of mortality, compared to those who were classified as obese but fit (24). This supports the current study, as a significant increase was found in individual's CRF (+12% in treatment group), whilst only a small change was found in waist-to-height ratio. This small change in waist-to-height ratio with regular exercise is consistent with previous studies (1), and may be explained by an increase in caloric intake to meet the extra energy expenditure demand. Likewise, there was a slight reduction in CRF within the control group. Research suggests that sedentary behaviour can cause reductions in CRF over time. This finding is supported by a study by Ekblom et al (9), who examined the effects of sedentary behaviour on cardiometabolic risk, whilst taking CRF into account. This study found an association between greater time spent sedentary and higher levels of triglycerides, poorer levels of HDL-cholesterol and a larger waist circumference (9). As studies have shown, these metabolic risk factors can increase the risk of cardiovascular events and mortality (9).

Lastly, waist-to-height ratio is an effective indicator of poor cardiometabolic health and mortality (25). Waist-to-height ratio can predict levels of VAT which is considered to play a role in insulin resistance, lipid metabolism, inflammation, and diabetes (27). In comparison to waist circumference and body mass index (BMI), waist-to-height ratio has shown to be a more accurate predictor of abdominal obesity and thus the risk of cardiovascular mortality (25). A study by Hsieh et al (12), indicated that a cut-off of 0.5 is common in identifying those with a higher proportion of central obesity, but also higher incidences of coronary risk factors as well as greater sedentary behaviour. This relates to the results in the present study, whereby the treatment group were able to reduce their waist-to-height ratio from 0.5 to 0.49 (-2%), which places them now below the cut-off for greater risk of central obesity and cardiometabolic risk factors. A 1-year intervention study utilised combined lifestyle interventions including the Study of Lifestyle intervention and Impaired Glucose tolerance Maastricht intervention (SLIM intervention) to form the METSLIM intervention (4). This idea uses dietary and physical activity interventions to target cardiometabolic risk factors in socio-economically disadvantaged areas (5). The results showed small reductions in individuals waist-to-height ratio (5). However, these changes were much smaller than the present study, with only a 0.02 reduction (5). A limitation to this study included the subjective self-reporting on physical activity and lack of a personalized approach to exercise. This may have provided a strength in the present study, whereby larger reductions were seen in the intervention group over a shorter period of time (12 weeks vs 1 year), suggesting the possible benefits of personalized exercise prescription.

One limitation to the study is the fact that an important component of the FFI calculation was identified using predicted VO_2max, instead of a direct measurement of VO_2max. Direct measurement of VO_2max has been deemed the 'gold standard' measurement for determination of an individual's aerobic capacity. In contrast, predicted VO_2max protocols are based on the assumption of a linear relationship between factors such as oxygen consumption and heart rate (25). Direct measurements of VO_2max are obtained from a graded exercise test (GXT), whereby individuals exercise continuously until volitional exhaustion, inducing high physical stress (3). These methods utilise analysis of expired gas to calculate VO_2max (3). However, these protocols are time-consuming, costly, and often unfeasible in real-world settings (3). Therefore, submaximal testing is more commonly used to predict VO_2max when there is limited time, equipment is unavailable or when considered unsafe to exercise an individual to a high intensity (3). Accordingly, the current study chose to use a submaximal test to estimate VO_2max.

Another limitation to the study includes the fact that University students were responsible for correct administration of the exercise programs, along with the exercise tests. Although students were under direct supervision from qualified Exercise Physiologists, there may have been a small degree of error during these tasks. Secondly, there was no long-term follow up within the study; as such, only the short term (12-week) benefits of exercise can be analysed. Long-term follow-up may be beneficial in determining not only the long-term benefits of personalized exercise prescription, but whether cardiometabolic risk and mortality are reduced in the long-term.

Lastly, whilst waist-to-height ratio has stood out in recent years due to its superiority in predicting cardiovascular risk compared to BMI and waist circumference in both adults and children, it is a relatively new measure and further research is needed to validate its use in a clinical setting. Potential paths for future research may also look at more precise measurements of VAT which is becoming a more important risk factor for metabolic disease risk. This includes dual-energy X-ray absorptiometry (DXA) which relies on X-rays to determine body composition using equations. DXA is a widely used tool in clinical practice due to its precision, low radiation and time compared to magnetic resonance imaging & computed tomography scans and convenience. Furthermore, future research may utilise a direct measurement of VO_2max to determine FFI. As mentioned previously, direct measurement of VO_2max is considered the best approach to determining cardiorespiratory fitness in individuals. Therefore, future studies may adopt a protocol using an incremental exercise test, to gain a true measurement of individuals VO_2max in order to calculate FFI which may provide validation of the results in the current study.

One strength of the study was that all measures used are classified as valid and reliable tools which can be used in clinical practice. Both height, waist circumference and submaximal talk tests can readily be used in clinics due to their cost-effectiveness and non-invasiveness compared to traditional measures of cardiorespiratory fitness using metabolic carts. By using the talk test, clinicians are able to gain valid measures of client's ventilatory thresholds which can accurately pinpoint personalized training intensities and maximise training adaptations, which is imperative when aiming to reduce client cardiometabolic risk.

The findings from the study provides evidence to support the use of personalised exercise programming using the ACE IFT guidelines in improving FFI among sedentary adults. As the prevalence of cardiometabolic diseases are increasing, successful interventions must be employed to reduce the burden on our healthcare system. By using a personalised approach to exercise prescription, the study was able to facilitate favourable improvements in FFI, CRF and waist-to-height ratio which are factors that can contribute to a lower risk of developing cardiometabolic conditions and overall mortality. Consequently, monitoring factors such as FFI, waist-to-height ratio and CRF using the methods in this study could be employed into standardised approaches as they are inexpensive, time-effective, and easy to administer in clinical settings. By doing this, it may provide a valid way of measuring an individual's cardiometabolic risk, as well as an effective way to reduce that risk using personalised exercise interventions.

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