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The Effect of Low Volume Sprint Interval Training on Cardiorespiratory Fitness: study protocol for a definitive randomized controlled trial

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Abstract

Background: Prior studies show significant increases in cardiorespiratory fitness ($\dot{V}O_2max$) and other health-related outcomes in response to reduced exertion high intensity interval training (REHIT), yet these studies are characterized by small sample sizes which casts doubt on the true efficacy of this form of physical activity for enhancing fitness and health. We propose a definitive randomized controlled exercise training study in a large sample of inactive adults to examine the effects of REHIT on outcomes related to cardiometabolic health in comparison to a non-exercise control group.

Methods: After baseline testing, 120 inactive men and women ages 18 – 64 yr will be randomized to a non-exercising control group or undergo 12 wk of REHIT. Participants will be healthy, weight stable, and have BMI < 35 kg/m^2 and be required to maintain their habitual physical activity and dietary patterns during the study. Training will be supervised and performed 2 days per week. Changes in $\dot{V}O_2max$, body composition, and substrate metabolism will be monitored to assess adaptations in cardiometabolic health in response to REHIT. To assess the feasibility of REHIT, various perceptual measures including RPE, affective valence, and enjoyment will be recorded, and quality of life will be measured.

Discussion: Data from the current study will advance physical activity research by bolstering the implementation of REHIT which will contribute to reduced risk factors of cardiovascular disease and in turn, improved public health.

Trial registration: This protocol was prospectively registered with OSF (osf.io/wvcz4) on November 3, 2025 and Clinical Trials.gov (NCT07328568) on January 8, 2026.

Key words: sprint interval training; maximal oxygen uptake; cardiometabolic health; substrate metabolism; cardiac output; feasibility

Background

Low levels of physical activity (PA) and cardiorespiratory fitness (CRF) are significant issues for societal health. Current public health guidelines for adults recommend performing at least 150 min of moderate-intensity continuous training (MICT) or 75 min of vigorous exercise per week, and strength training on 2 or more days per week [1]. However, self-report data suggest that in 2020, more than 75% of adult Americans did not meet these minimum PA recommendations [2]. This is a major concern given that physical inactivity is the fourth leading cause of death worldwide [3]. It is well-documented that inactivity increases the risk of 40 chronic conditions or diseases [4], and that low maximal oxygen uptake ($\dot{V}O_2$max; the gold standard measure of CRF) is strongly associated with increased risk of future morbidity and all-cause mortality [5, 6]. Importantly, many large-scale studies have reported $\dot{V}O_2$max to be a more powerful predictor of risk for future morbidity and all-cause mortality than more traditional risk factors such as smoking, hypertension, obesity, high cholesterol, and insulin resistance [7-10]. For population-level health, the largest benefits from improved PA and CRF are gained by the least fit individuals, with even small increases in fitness shown to improve health [8]. Despite exercise being the only viable means to improve $\dot{V}O_2$max, it remains underutilized for primary disease prevention [11, 12].

Applicability of High Intensity Interval Training (HIIT)

Reported barriers to exercise include lack of time, lack of knowledge about exercise, poor local facilities, lack of transportation, costs, and inclement weather [13-15]. Of these barriers, the

most commonly reported is perceived lack of time. Consequently, there has been increasing interest in identifying effective, time-efficient exercise interventions compared to current PA recommendations. In the last 20 yr, interventions involving submaximal high-intensity interval training (HIIT; typically ~10x1-min efforts) and supramaximal sprint interval training (SIT; typically 4-6x30-s 'all-out' cycle sprints) [16] have been proposed as time-efficient alternatives to MICT. The generation of high intensities during HIIT and SIT provides a potent metabolic stimulus which enables substantial adaptive responses with a reduced volume of exercise versus MICT [17]. Hundreds of studies have examined changes in health and fitness to HIIT and SIT in healthy, active, and sedentary adults and patients with cardiovascular disease, diabetes, stroke, hypertension, and cancer [18]. These data show that HIIT and SIT significantly improve key health markers including $\dot{V}O_2$max, insulin sensitivity and glycemic control, blood pressure, body composition, and blood lipids [19]. Several meta-analyses demonstrate that HIIT and SIT can provide health benefits similar to, or better than, MICT [20-22], further supporting the efficacy of these protocols.

Criticisms of HIIT and SIT

Despite the many health benefits of HIIT and SIT shown in lab-based studies, criticisms concern the suitability of such protocols to be implemented as real-world exercise interventions for improving general health and wellbeing [23-25]. First, most studies examining effects of HIIT and SIT used small sample sizes, questioning the reliability of these findings [26]. Second, while the total volume of exercise in HIIT or SIT sessions is low, the need for recovery periods following each interval means that the total time commitment of the most commonly studied HIIT and SIT protocols is ~66-93 min/wk [17] which is not a time-efficient alternative to current vigorous PA recommendations. Third, the multiple intense efforts make most HIIT and SIT

protocols demanding, resulting in high ratings of perceived exertion [27] and reductions in affective valence (i.e., this exercise makes you 'feel bad') [28]. These effects have been proposed to result in reduced enjoyment and consequently reduced uptake of, and adherence to, these protocols [29].

The Case for Reduced-Exertion High-Intensity Interval Training (REHIT)

Surprisingly, despite the fact that time efficiency is widely stated as the main rationale for studying the health benefits of HIIT and SIT, few studies have determined if protocols with fewer and/or shorter sprints are effective. Prior data demonstrated that mechanisms mediating improved glycemic control and insulin sensitivity with SIT [30] may be related to the rapid glycogenolysis occurring during the first half of the first two 30-s sprint repetitions [31]. These authors created a protocol having two 20-s all-out sprints within a 10-min exercise session called 'reduced-exertion high-intensity interval training' (REHIT) [32]. In a small RCT (n=15 REHIT/n=14 control), there was a significant 28 % improvement in the Cederholm Index of insulin sensitivity in men [32] as well as a significant increase in $\dot{V}O_2$max in both men (+15%) and women (+12%).

Subsequently, the efficacy of the 10-min REHIT protocol to improve $\dot{V}O_2$max has been confirmed by these authors [33-37] and in other independent laboratories [38-40]. On average, $\dot{V}O_2$max increases ~10% following 6 wk of REHIT and by ~19% after 12 wk (**Table 1**). Such improvements in $\dot{V}O_2$max are associated with risk reductions of 30 and 38 % for all-cause and cardiovascular disease mortality, respectively, if maintained [41]. Improvements in $\dot{V}O_2$max are significantly attenuated if sprint duration is reduced from 20 to 10 s per sprint [35], but not if training frequency is reduced from 3 or 4 days/wk to 2 days/wk [33].

With a total time commitment as low as 20 min/wk, REHIT is a genuinely time-efficient intervention, circumventing the most commonly reported perceived barrier to exercise of lack of time. Moreover, REHIT may enable other barriers to exercise to be addressed. First, a common criticism of HIIT and SIT protocols is that, even if they are associated with health benefits, they are unlikely to be taken up and adhered to by the general public because the high exercise intensities may be associated with a rapid decrease in affective valence (e.g., exercise makes you 'feel bad'), which will cause low exercise enjoyment [26-29]. Although the association between decreases in affective valence and exercise enjoyment is tenuous [28,42], as is the link between changes in affective valence and future exercise behavior [43], the most commonly studied HIIT and SIT protocols are associated with larger decreases in affective valence than MICT, so they are perceived as more unpleasant [28]. However, we demonstrated that the interaction between sprint intensity and sprint volume determines the magnitude of the affective response to HIIT and SIT [28]. For SIT, the typical reduction in affective valence is substantially attenuated by reducing sprint duration and repetitions. In fact, the in-task decrease in affective valence with REHIT is similar to that observed following a duration and intensity of MICT commensurate with current PA guidelines, and the majority of our research participants have a preference for REHIT versus MICT [28,35,44]. In addition, a recent study compared perceptual responses to a 10-min REHIT session between adults with above (n=43) versus below-average CRF (n=42) [45] showed no significant difference in enjoyment, perceived exertion, or affective valence between groups. Furthermore, affective valence remained positive, suggesting that REHIT does not make adults 'feel bad.'

Lastly, concerns have been raised about the safety of HIIT and SIT [25], but to date no studies indicate that these protocols are unsafe for individuals without contraindications to MICT. In our

REHIT studies, we have not observed any serious adverse events in inactive adults [33-37, 44-45] or in those with type 2 diabetes [34]. All exercise including REHIT is associated with some risk, but current data do not show that HIIT/SIT or REHIT increase risk for the population of insufficiently active adults without clear contraindications to exercise in general.

Overall, there is accumulating evidence for the sizable health benefits of REHIT and the acceptability and safety of the intervention. Other commonly studied HIIT and SIT protocols have major disadvantages that prevent real world implementation (i.e.: not time-efficient, too strenuous, induce feelings of displeasure), but REHIT may circumvent most or all of these barriers. REHIT is at least as efficacious at improving key health markers as MICT, as enjoyable as MICT, and not associated with more negative affective responses during exercise versus MICT. We acknowledge that it is unlikely that any single intervention can remove the perceived barriers to exercise for all adults, but REHIT has the potential to enable a meaningful proportion of adults to reap the health benefits of exercise through a manageable, time-efficient intervention. REHIT represents a promising protocol for further study and subsequent inclusion in PA recommendations as a feasible alternative or adjunct to moderate or vigorous-intensity exercise as currently promoted. Thus, there is a strong justification to conduct a fully powered RCT to provide a definitive answer to the question whether REHIT induces a clinically meaningful improvement in $\dot{V}O_2$max and is perceived as feasible/acceptable.

Objectives

The study objectives included 1) to examine changes in $\dot{V}O_2$max in response to 12 wk of REHIT in inactive adults; 2) to examine changes in the metabolic response to 12 wk of REHIT in inactive adults, which has yet to be studied; and 3) to examine the feasibility and acceptability of REHIT in inactive adults. It was hypothesized that compared to a control group, a significant

increase in $\dot{V}O_2$max will occur, which will be identified through incremental exercise testing performed before and after training. It is also hypothesized that compared to a control group, a significant increase in exercise fat oxidation will occur, and that REHIT will be well-tolerated, safe, and perceived as enjoyable.

Methods

Experimental design: This study is a definitive randomized controlled trial using a repeated measures design, as participant responses to 12 wk of REHIT will be compared to those in a non-exercising control group. Baseline testing will consist of assessments of body composition, VO_2max, and substrate metabolism. After baseline testing, participants will be randomized in a 1:1 ratio to REHIT or control by a statistician who will use a computer-generated random sequence program. REHIT will consist of 2 d/wk of training on a cycle ergometer for 12 wk, with reassessment of VO_2max performed during week 6 and at the end of training. Participants randomized to the control group will be re-tested in weeks 6 and 12 and be given the option to subsequently undergo REHIT. During the study, habitual physical activity and dietary patterns will be monitored and participants will be required not to change these behaviors. The study protocol was approved by the CSU—San Marcos Institutional Review Board (#2313242-2 on September 12, 2025) and has been registered with OSF (osf.io/wvcz4) on November 3, 2025 and Clinical Trials.gov. (NCT07328568) on January 7, 2026. The study design is consistent with the SPIRIT guidelines [46] and a SPIRIT Figure is included below as Figure 1. At this time, there are no plans to change this study protocol, although if needed, formal procedures will be followed and submitted to the campus IRB for approval. In addition, there is no plan to conduct additional studies using data acquired in this study.

Activity/Assessment	**Baseline**	**6 weeks**	**12 weeks**	**Weekly**
Eligibility screening	X			
Informed consent	X			
VO_2max testing	X	X	X	
CO testing	X	X	X	
Substrate metabolism	X	X	X	
Body composition	X		X	
Feasibility of REHIT				X
Physical activity and dietary patterns	X	X	X	
Interventions				
REHIT				X
Control	X	X	X	
Measures				
Expired gases	X	X	X	
Thoracic impedance	X	X	X	
Psychological responses				X
IPAQ and diet log	X	X	X	

VO_2max = maximal oxygen uptake CO = cardiac output; REHIT = reduced exertion high intensity interval training; IPAQ = International Physical Activity Questionnaire

Figure 1: SPIRIT Figure.

Study setting and oversight: All participant interactions in this study will be completed in the Department of Kinesiology at California State University—San Marcos. Data collection will begin in January 2026, and up to 60 adults will undergo REHIT during the 3 yr study duration.

The Principal Investigator Dr. Todd A. Astorino will be responsible for oversight including management of all facets of the study, such as participant enrollment, training of study staff, data collection and analysis, and data storage and dissemination. Dr. Michael Joyner from the Mayo Clinic in Rochester, MN is serving as the NIH appointed Safety Officer who will perform annual reviews of safety issues and adverse events related to the study. The PI's Institution does not have a Data Safety Monitoring Board, yet one will be developed if the funder requests this.

Participant recruitment and pre-screening: Recruitment will be initially performed through word-of-mouth and ads placed on campus as well as in local and regional schools, newspapers, workplaces, physician offices, and on Facebook and Instagram. A website will be developed to describe the study. If recruitment is poor in the early stages of the study, the Investigators will employ services including Trialfacts or Wayturn to enhance participant recruitment. Because of the long duration of participation equal to 12 wk, recruitment and eventual enrollment in the study will need to be appropriately timed to prohibit the possibility of absences from training or missed assessments due to holiday breaks, summer vacation, etc.

Granting of informed consent and pre-screening will be overseen by the Primary Investigator and will include acquisition of demographic traits and review of study requirements including time commitment, maintenance of habitual diet and activity, and participant in/exclusion criteria. These data will be maintained by the Primary Investigator using codes to preserve anonymity.

Randomization: After baseline testing, the Principal Investigator will provide each participant's age, sex, and code to the statistician. Participant randomization to REHIT or control will be computer generated and performed by the study statistician who will have no interaction with participants or role in exercise training or testing. Participants will be randomized using simple randomization according to the NIH Clinical Trial Randomization tool. All research personnel will not have access to this randomization sequence. Once randomized, the statistician will provide the Principal Investigator with the group assignment for each participant via email who will use this information to enroll participants. The Principal Investigator and all Research personnel who interact with participants will not be blinded to group allocation.

Participants: We will recruit healthy, low-active men and women aged 18-64 yr until 120 participants (60 controls and 60 who undergo REHIT) have completed the study, whose protocol

is shown in Figure 2. Eligible participants will be free of disease and will not have been involved in structured exercise training in the last year. Adults over 64 yr old are excluded as the NIA and CDC classify 'older adults' as > 65 yr, and there is increased risk of adverse events of exercise testing in participants 65 yr and older [47]. Activity status will be verified using the International Physical Activity Questionnaire (IPAQ) [48]. Based on our experience in similar studies, we expect a dropout rate of 10 - 15%. Control participants will complete assessments at baseline and again at 6 and 12 wk, after which they will be offered the opportunity to partake in 12 weeks of REHIT if they choose. Exclusion criteria include answering "yes" to any question on a standard Physical Activity Readiness Questionnaire (PARQ), onset of type 2 diabetes, CVD, blood pressure >160/100 mm Hg at rest, pregnant or plans to become pregnant, use of medications altering our outcomes, and severe medical conditions that contraindicate exercise training. We will exclude adults who diet or plan to lose weight and those with BMI>35 $kg \cdot m^{-2}$, which may reduce the $\dot{V}O_2max$ response to training [49].

Trial outcomes: Figure 1 shows the main outcomes acquired in this study. The primary outcome is the change in $\dot{V}O_2max$ measured using indirect calorimetry, which will be assessed at baseline and then at 6 and 12 wk of the protocol. The overall change in $\dot{V}O_2max$ will be compared between the REHIT and control groups. During this assessment, secondary outcomes including CO and substrate metabolism will be acquired and they will also be compared between groups. Body composition, another secondary outcome, will be measured at baseline and at 12 wk using bioelectrical impedance analysis, with these data being compared between groups. Lastly, psychological responses to REHIT will be acquired weekly using validated surveys, and their changes will be analyzed across the 12 wk of training.

Baseline assessment: To address hypothesis 1, $\dot{V}O_2$max will be assessed using the gold standard incremental cycling test to exhaustion with continuous gas exchange analysis. Before $\dot{V}O_2$max testing, participants will refrain from intense physical activity for 36 hours, be well-rested and hydrated, and will arrive after an overnight fast or at least 6 hours after a light meal which will be confirmed via a survey. Body mass and height will be determined with a balance beam scale and stadiometer, and body composition (%BF, FM, and FFM) will be determined using an InBody analyzer (Model 270S, Cerritos, CA). Then, $\dot{V}O_2$max and maximal workload will be measured on a cycle ergometer (Lode Corival, Groningen, the Netherlands) with simultaneous acquisition of gas exchange data using a metabolic cart (ParvoMedics True One, Sandy, UT). The typical error in $\dot{V}O_2$max testing in our lab is 0.11 L/min [50] which is similar to other studies [51, 52]. During the test, workload will start at 30 W (women) or 40 W (men), after which power output will increase by 15-20 $W \cdot min^{-1}$ until volitional fatigue (pedal cadence <50 rpm). $\dot{V}O_2$max will be determined as the mean of the two highest 15 s values at exercise termination, and accepted if two or more of the following criteria are met: 1) volitional exhaustion, 2) a plateau in $\dot{V}O_2$ despite increasing intensity, 3) RER>1.10, and 4) maximal heart rate within 10 beats of the age-predicted maximum (i.e., 220-age). At the end of week 6, $\dot{V}O_2$max will be re-assessed to examine the early change in cardiorespiratory fitness. Two to three days after the final training session and at the same time of day within participants, $\dot{V}O_2$max will be re-measured using identical procedures.

To better understand mechanisms underpinning the change in $\dot{V}O_2$max with REHIT, an impedance cardiograph device (Physioflow Enduro, Manatec, Strasbourg, France) will be used to evaluate hemodynamic function. This method detects changes in transthoracic impedance during the cardiac cycle to calculate stroke volume (SV), which is multiplied by heart rate (HR) to

estimate cardiac output (CO). The method is valid and reliable for assessment of CO at rest and during exercise up to $\dot{V}O_2$max [52 - 54]. In our lab, the typical error for COmax in response to $\dot{V}O_2$max testing is 1.5 $L \cdot min^{-1}$ [50, 55]. All participants will undergo this assessment during all tests of $\dot{V}O_2$max. Arteriovenous O_2 difference (avO_2diff) will be calculated from the reversal of the Fick Equation, $\dot{V}O_2 = CO \times avO_2diff$.

To address hypothesis 2, participants will complete a brief bout of low-intensity submaximal exercise preceding the assessment of $\dot{V}O_2$max. The bout will also serve as familiarization to acquisition of gas exchange data and provide a warm-up to the $\dot{V}O_2$max test, and should have no impact on resultant determination of $\dot{V}O_2$max.

Participants will complete a minimum 6-hour fast before testing, as this seems to be the minimum duration needed to not impact determinations of substrate metabolism [56] due to elevations in blood glucose induced by a prior meal. Participants tested in the morning (07:00-10:00 am) will have a longer fast duration since they will not eat during the morning of testing, resulting in a potential for greater reliance on lipid as fuel. Participants will be instructed not to walk or bike to the laboratory and be well-rested, hydrated, and refrain from strenuous activity for 36 hours pre-bout. To standardize dietary practices, participants will record their dietary intake on a written log for 36 hr before this trial, which will be repeated for the 6 and 12 wk assessments in the training group and at equivalent timepoints for the controls. This is done as disparate dietary patterns can impact the muscle glycogen pool and potentially impact estimates of substrate metabolism [57].

Pre-exercise, resting heart rate and blood pressure will be determined using methods previously described [50, 55]. Subsequently, a fingertip blood sample will be obtained to measure blood glucose concentration (Bayer Contour, Ascencia, Parsippany, NJ) and blood

lactate concentration using a portable device (Lactate Plus, Sports Research Group, New Rochelle, NY). Participants will sit on the cycle ergometer while resting gas exchange data are acquired for 3 min, to enable stable estimates of $\dot{V}O_2$ and $\dot{V}CO_2$, and in turn substrate metabolism. Subsequently, they will complete 10 min of cycling at intensities equal to 30 or 40 W in women and men, respectively. In inactive adults, these intensities should elicit approximately 50-60% HRmax which induces the highest rate of lipid oxidation [58]. $\dot{V}O_2$ and $\dot{V}CO_2$ will be averaged over the last 5 min of the bout and used to estimate respiratory exchange ratio (RER) and lipid and CHO oxidation (in $g \cdot min^{-1}$) using the Frayn equations [59], where lipid oxidation (g/min^{-1}) = $1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2$, and CHO oxidation ($g \cdot min^{-1}$) = $4.55 \times \dot{V}CO_2 - 3.21 \times \dot{V}O_2$. Blood glucose and lactate concentrations will be determined using identical procedures 3 min after the end of this bout.

To address the feasibility of REHIT (aim 3), during the last session of each week of REHIT, we will monitor perceptual responses which are related to long-term adherence [60]. Rating of perceived exertion [61] and affective valence [62], validated measures of perceived exertion and pleasure, will be measured prior to and after each sprint and midway in recovery from each sprint to assess the pattern of changes in perceptual responses during REHIT. Ten minutes post-REHIT, participants will be asked to rate their enjoyment using the 18-item PACES questionnaire [63], which is widely used to assess the enjoyment response to acute MICT and HIIT [64 - 67]. This scale has 11 negatively-worded and seven positively-worded items that participants will rate on a bipolar scale from 1 to 7, indicating how they feel about the exercise they completed. To assess the real-world feasibility of training, we will record compliance by calculating the percentage of training sessions completed. In addition, onset of exercise-related adverse events and/or injuries will be recorded, and in event of participant withdrawal, they will

be asked what reason(s) led to dropout. At the end of training, participants' confidence in their ability to continue training for four more weeks will be assessed using a 1-item measure of self-efficacy [68], which asks '*How confident are you that you can perform the bouts of exercise just like the ones you have completed, each week for the next four weeks*? Responses will be scored on a scale of 1 (Not at all confident) to 9 (Extremely confident). Acceptability of training will be assessed using an 11-item questionnaire scored on a 1-5 Likert scale (strongly disagree to strongly agree) [69]. Results in inactive adults [70] show that 8 wk of HIIT was enjoyable and increased subsequent physical activity, suggesting that HIIT can promote sustainable participation in physical activity. Lastly, health-related quality of life (HRQoL) will be assessed pre- and post-training using the 36-item short-form questionnaire [71]. This survey evaluates self-reported health status and function, with lower scores indicating higher levels of disability. Primary and secondary outcomes assessed in this study are shown in Table 1.

Implementation of REHIT: Training will begin $\geq$ 48 h after pre-testing and follow regimens used in inactive adults completing REHIT which significantly increased $\dot{V}O_2max$ [32 - 40]. We will employ 12 wk of training, since duration greater than 6 wk is better to portray the adaptive response to training. All sessions will be supervised and performed on the CAROL cycle ergometer (Integrated Health Partners Limited, Decatur, GA). Heart rate (Polar Electro, Woodbury, NY) and peak/mean/end power output (using the cycle ergometer's software) will be recorded during all sessions to characterize the physiological load of REHIT. Adherence will be quantified as the frequency of total sessions (in %) out of 24.

REHIT will consist of 2 min of unloaded pedaling, followed by an all-out sprint, 3 min of unloaded pedaling, a second all-out sprint, and a further 4 min of unloaded pedaling. Sprint duration will increase from 10 s in Week 1 to 15 s in Week 2, and 20 s in the remaining 10

weeks. Sprint resistance will be set at a load equal to 5% of body mass. Participants will increase their pedal frequency to maximal ~2-3 s prior to applying the resistance at the start of the sprint. Verbal encouragement will be provided to support participants to maintain the highest pedal frequency they can achieve throughout each sprint. Sessions will be spaced equally over each week whenever possible. This exercise regimen was shown to be safe, effective, and well-tolerated in inactive adults [32 - 40, 44, 45]. Sprint interval training elicits intensities above that attained at $\dot{V}O_2$max, and it is likely that the supramaximal power output and rapid glycogen degradation potentiate molecular signals related to inducing significant increases in $\dot{V}O_2$max, insulin sensitivity, and lowered body fat despite the low volume of up to 40 s of high-intensity exercise per session [31, 39].

Monitoring of Physical Activity and Dietary Intake: Habitual physical activity can impact the $\dot{V}O_2$max response to exercise training [72], so participants' physical activity will be assessed before the intervention and during weeks 6 and 12 using the International Physical Activity Questionnaire (IPAQ) [48]. Participants will be asked not to perform additional structured physical activity during the study or change their dietary habits. They will complete a 4-day food log with 2 weekend days (Diet Frequency Questionnaire III, National Cancer Institute) at baseline and in week 12 to assess dietary intake.

Adverse events and study discontinuation: During the study, onset of dizziness, lightheadedness, and pain in participants will be monitored. Any serious adverse events above and beyond typical responses to VO_2max testing and REHIT will be reported to the University IRB. We anticipate that some participants will not complete all requirements of the study, for example, if they request to stop participating due to injury or inability to meet the time requirements of the study,

maintain their habitual dietary and activity patterns, etc. We anticipate that participants will experience no harms in this study, so no post-trial care will be provided.

Sample size estimation: In a pooled analysis of 117 sedentary participants performing 6 wk of REHIT, we established a mean increase in $\dot{V}O_2$max of 9.3% with a standard deviation of individual responses (SD_{IR}) of 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$ [73]. This was similar to the 10 % increase in $\dot{V}O_2$max with an SD_{IR} of 2.5 $mL \cdot kg^{-1} \cdot min^{-1}$ which was observed in a cohort of inactive individuals performing 6 wk of supervised SIT (n=136, METAPREDICT [74], and to the SD_{IR} of the training response reported by the HERITAGE Family Study following 20 wk of MICT (n=720; SD=2.7 mL·kg-1.min^{-1} [75]. This suggests that these are "typical" values for between-subject variability in the $\dot{V}O_2$max response following training and in turn, can be considered suitable data for use in the sample size calculation for this study.

An increase in $\dot{V}O_2$max equivalent to 1 MET (3.5 $mL \cdot kg^{-1} \cdot min^{-1}$) is expected to reduce risk of all-cause and CVD mortality by 13 % and 15 %, respectively [8]. In the absence of a universally accepted smallest clinically meaningful effect for the primary outcome measure of $\dot{V}O_2$max used in the present study, we define the smallest worthwhile difference in the change in $\dot{V}O_2$max between the intervention and control groups as 1.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (~4.5% increase in $\dot{V}O_2$max), equivalent to a risk reduction for CVD mortality of ~8%. Thus, in order to be able to detect the smallest worthwhile difference with an effect size of d=0.60, we need n=120 participants in total (with n=60 participants randomized to the training group and n=60 to the control group) with alpha=0.05 and power of 90%. A secondary analysis of sex differences in the response to REHIT will be performed, sufficiently powered to detect a large effect size (d=0.80) with alpha=0.05 and a power of 80%. We will recruit participants until the target has been achieved.

Despite dozens of studies exhibiting beneficial effects of exercise training on lipid oxidation, no study has identified a smallest worthwhile change for this outcome. However, with a sample size of n=120 established for the primary outcome measure of training-induced change in $\dot{V}O_2$max, our study will be sufficiently powered to detect changes in lipid oxidation (Aim 2) with a medium effect size of *d*=0.52, with alpha=0.05 and power of 80%.

Exercise enjoyment as measured using the PACES questionnaire is only assessed in the intervention group, with changes analysed using a repeated measures ANOVA. The study will be sufficiently powered to detect changes in exercise enjoyment (Aim 3) with a small effect size of *f*=0.14, with alpha=0.05 and power of 90%.

Data analysis: Data will be expressed as mean ± standard deviation and will be analyzed using SPSS V. 27.0 (IBM, Armonk, NY). All data will be anonymous. The Shapiro-Wilks test will be used to assess normality of each variable. Changes in outcomes will be analyzed using two-way mixed-model ANOVA, with time as a within-subjects factor (pre- vs. 6 wk vs. 12 wk) and group (REHIT vs. control) as a between-subjects factor. Changes in exercise enjoyment, RPE, and pleasure will be analyzed using arepeated measures ANOVA. If a significant F-ratio occurs, Tukey's *post hoc* test will be used to identify differences between means. The Greenhouse-Geisser correction will be used if the sphericity assumption of equal variances across groups is not met. Unpaired t-test will be used to identify baseline differences in age, BMI, and/or $\dot{V}O_2$max between groups. If there is a baseline difference in any outcome between groups, it will be used as a covariate in our analysis. Cohen's *d* will be used as a measure of effect size and represented using these values: 0.20-0.49 = "small," 0.50-0.79 = "moderate," and $\geq$0.80 = "large". Both intention-to-treat analysis (including all randomized participants with data for baseline and follow-up timepoints) and per protocol analysis (including all participants with

>75% of prescribed sessions completed) will be performed. If a participant withdraws from the study during the training intervention, that participant's data will be omitted from the final statistical analysis.

Dissemination of study data: Participants will be informed of their data upon completing the study and there are no restrictions on publishing these data, which will be disseminated in peer-reviewed Journals. Manuscripts concerning these data will be placed on a public registry (Clinical Trials.gov) upon study completion. The Authors of this protocol will serve as the co-Authors on manuscripts resulting from this study. No professional writers will be used in developing said manuscripts.

Discussion

Physical inactivity is one of the primary public health challenges of the 21st century [76], the fourth leading risk factor for global mortality, and is related to increased risk of heart disease, type 2 diabetes, hypertension, stroke, and some cancers [77]. Ding et al. [78] estimated that in 2013, there were $28 billion in direct and indirect costs in the US attributed to inactivity. It is apparent that regular PA enhances cardiometabolic health through its positive effects upon $\dot{V}O_2$max [79 - 81], blood pressure [82 - 84], body composition [85, 86], and glycemic control [87, 88]. As current PA recommendations involving a relatively large volume of moderate or vigorous intensity exercise are poorly adhered to [2, 80], there is a need to explore alternatives that address the most common (perceived) barriers to exercise, such as lack of time. Prior research conducted in active and inactive adults shows that HIIT and/or SIT are efficacious, time-efficient interventions, but despite a low exercise volume per training session, these protocols are not as time-efficient as often claimed, and invariably induce marked fatigue, thus reducing their application to the general adult population [23].

Moreover, a growing body of evidence supports that the genuinely time-efficient REHIT protocol is effective at improving key health markers, acceptable, and implementable in real world, ecologically valid settings. However, existing data showing the benefits of REHIT have been acquired from studies with small sample sizes. Thus, there are grounds for criticisms related to the true impact of REHIT. To address this debate, this adequately powered study will examine the feasibility and efficacy of REHIT at improving outcomes related to cardiometabolic health in inactive adults. The study will test the feasibility and efficacy of extremely time efficient exercise training in inactive adults with a primary goal to improve participants' cardiometabolic health, which is directly related to prevention of cardiovascular disease. Overall, this RCT has tremendous public health relevance as it will greatly advance understanding of exercise interventions that may be used as alternatives to current PA recommendations.

Trial Status

The trial described in this manuscript is ongoing with the first participant to be recruited in December 2025, with study completion arising in September 2028.

List of Abbreviations

avO_2diff	arteriovenous oxygen difference
BMI	body mass index
CO	cardiac output
CVD	cardiovascular disease
FFM	fat free mass
FM	fat mass

HIIT	high intensity interval training
HR	heart rate
IPAQ	international physical activity questionnaire
L	liters
mL	milliliters
MICT	moderate intensity continuous training
PA	physical activity
PACES	physical activity enjoyment scale
PARQ	physical activity readiness questionnaire
RCT	randomized controlled trial
REHIT	reduced exertion high intensity interval training
RER	respiratory exchange ratio
RPE	rating of perceived exertion
SIT	sprint interval training
SV	stroke volume
$\dot{V}CO_2$	volume of carbon dioxide production
$\dot{V}O_2$	volume of oxygen consumption
$\dot{V}O_2max$	maximal oxygen consumption
W	watt

Declarations

The Authors have nothing to declare.

Ethics approval and consent to participate: This protocol (#2313242-2) was approved by the CSU—San Marcos Institutional Review Board on September 12, 2025; written informed consent will be obtained from all participants enrolled in this study. In addition, the trial was registered with OSF (osf.io/wvcz4) on November 3, 2025 and with Clinical Trials.gov (NCT07328568) on January 7, 2026.

Consent for publication: Not applicable.

Availability of data and materials: The final set of aggregate data acquired from this study will be posted to a public registry. Prior to placement in this registry, the data will be made anonymous.

Competing interests: The authors declare that they have no competing interests.

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Authors' Contributions: TAA is the Primary Investigator and along with NBJV, designed the protocol and developed this manuscript. TAA developed the informed consent document and protocol for human subjects approval and will acquire all data described in this protocol and manage the day-to-day progress of this study. RSM assisted with study design and creating the research protocol and developing this manuscript. All authors read and approved the final manuscript.

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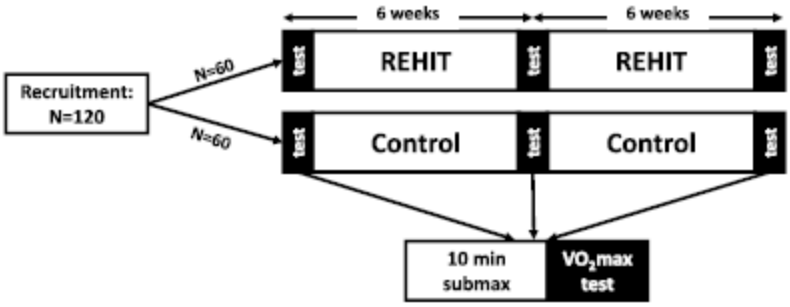

Table 1: Studies demonstrating improvements in $\dot{V}O_2$max with REHIT

Study	Duration (wk)	Condition	Change in $\dot{V}O_2$max
Metcalfe et al. (2012) [32]	6	8 women and 7 men 3 sessions/wk	+ 12 – 15 %
Gillen et al. (2014) [38]	6	7 women and 7 men 3 sessions/wk	+ 12 %
Metcalfe et al. (2016) [36]	6	35 women and men 3 sessions/wk	+ 9 – 10 %
Gillen et al. (2016) [39]	12	9 men 3 sessions/wk	+ 19 %
Ruffino et al. (2017) [34]	8	16 men with type 2 diabetes 3 sessions/wk	+ 7 %
Nalcakan et al. (2018) [35]	6	19 men and 17 women 3 sessions/wk	+ 10 %
Cuddy et al. (2019) [40]	8	Workplace-based intervention in 12 men and women 3 sessions/wk	+ 12 %
Metcalfe et al. (2020) [37]	6	Workplace-based intervention in 13 men and women 2 sessions/wk	+ 7 %
Thomas et al. (2020) [33]	6	29 men and 13 women 2 sessions/wk	+ 10 %
	6	3 sessions/wk	+ 8 %
	6	4 sessions/wk	+ 7 %
Bostad et al. (2021) [52]	12	6 men and 9 women 3 sessions/wk	+ 21 %
Bostad et al. (2023) [89]	12	10 men and 10 women 3 sessions/wk	+ 9 %
Hu et al. (2025) [90]	12	82 men 5 sessions/wk	+ 15 %
Renwick et al. (2025) [91]		7 men and 10 women 3 sessions/wk	+ 17 %

Table 2: Primary and secondary outcomes acquired in this study.

Outcome measure	Method of analysis	Frequency
$\dot{V}O_2$max	Incremental cycling during which gas exchange data are acquired	0, 6, and 12 wk in REHIT and 0, 6, and 12 wk in CON
COmax	Thoracic impedance during the $\dot{V}O_2$max test	0, 6, and 12 wk in REHIT and 0, 6, and 12 wk in CON
SVmax	Thoracic impedance during the $\dot{V}O_2$max test	0, 6, and 12 wk in REHIT and 0, 6, and 12 wk in CON
Fat and CHO oxidation (g/min)	$\dot{V}O_2$ and VCO_2 will be acquired from 10 min of submaximal cycling preceding the $\dot{V}O_2$max test. These values will be calculated using the Frayn equations.	0, 6, and 12 wk in REHIT and 0, 6, and 12 wk in CON
Body composition	In-Body BIA	0 and 12 wk in REHIT and CON
BLa	Portable analyzer used to sample blood from a fingertip	Weekly during REHIT
RPE	Borg 6 – 20 scale	Weekly during REHIT
Affective valence	Feeling scale (+ 5 to -5)	Weekly during REHIT
Enjoyment	Physical Activity Enjoyment scale	Weekly during REHIT
HR	Polar monitor	During all REHIT sessions

$\dot{V}O_2$max = maximal oxygen uptake; REHIT = group who performs reduced exertion high intensity interval training; CON = non exercising control group; CO = cardiac output; SV = stroke volume; CHO = carbohydrate; $\dot{V}O_2$ and $\dot{V}CO_2$ = oxygen uptake and carbon dioxide production; BIA = bioelectrical impedance analysis; BLa = blood lactate concentration; RPE = rating of perceived exertion; HR = heart rate