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Maximal Strength Training Increases Metabolic Energy Expenditure in Sedentary Adults Classified as Obese

Robert E. Anderson III
University of Kentucky, reanderson3@gmail.com
Author ORCID Identifier:
https://orcid.org/0000-0002-0008-7754
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Robert E. Anderson III, Student

Dr. Kyle Flack, Major Professor

Dr. Dawn Brewer, Director of Graduate Studies

MAXIMAL STRENGTH TRAINING INCREASES METABOLIC ENERGY EXPENDITURE IN SEDENTARY ADULTS CLASSIFIED AS OBESE

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master ofScience in Nutrition and Food Systems in the College of Agriculture, Food and Environment at the University of Kentucky

By

Robert E. Anderson III

Lexington, Kentucky

Chair: Kyle Flack, Ph.D., R.D., L.D

Lexington, Kentucky

2022

https://orcid.org/0000-0002-0008-7754

ABSTRACT OF THESIS

MAXIMAL STRENGTH TRAINING INCREASES METABOLIC ENERGY EXPENDITURE IN SEDENTARY ADULTS CLASSIFIED AS OBESE

Background: Metabolic adaptations reduce resting and non-resting energy expenditure to account for approximately 120 kcal/day. Weight loss promotes greater skeletal muscle efficiency, reducing the energy cost of physical activity and is correlated with declines in skeletal muscle glucose oxidation. Maximal Strength Training (MST) has the potential to upregulate glucose utilization and may offset these metabolic adaptations. Objective: To determine if MST offsets markers of metabolic adaptation by increasing resting and non-resting energy expenditure in sedentary individuals classified as obese. Methods: Five (5) participants (2 females, 3 males), ages 18-35 years, with obesity (BMI 30–45 kg/m2) were enrolled in an 8-week MST intervention. Participants completed 3 MST sessions per week on non-consecutive days. Resting Energy Expenditure (REE) via indirect calorimetry and Skeletal Muscle Work Efficiency (SME) via graded exercise cycle ergometer test were assessed pre and post intervention. Results: REE (in kcal/kg FFM/24hrs) increased from 30.51 at baseline to 37.37 post (a 22.48% increase, $P=0.02$) with no significant changes in Body Fat (BF) or FFM. Skeletal Muscle Efficiency (SME) calculated as (watts converted to kcal/min)/ [energy expended (kcal/min) – resting energy expenditure (kcal/min) adjusted for fat-free mass) trended towards a significant decrease at 25 W (-6.51%, $P=0.435$) and at 50 W (-4.01%, $P=0.579$). Conclusions: These results suggest that an 8-week MST intervention can significantly increase REE in individuals classified as obese and shows trends towards decreasing SME at low intensity exercise. Therefore, MST may be a useful strategy to attenuate metabolic compensation.

KEYWORDS: maximal strength training, metabolic rate, adaptive thermogenesis, skeletal muscle efficiency

Robert E. Anderson III

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By

Robert E. Anderson III

University of Kentucky

Kyle Flack, PhD, RD

Director of Thesis

Dawn Brewer, PhD, RD

Director of Graduate Studies

02/14/2022

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Chapter One: Introduction

Background

Over 70% of U.S. adults are classified as either overweight (Body Mass Index (BMI) 25-29.9) or obese (BMI > 30) (1). Obesity is a major risk factor for the development of type 2 diabetes mellitus, pre-diabetes, cardiovascular disease, coronary artery disease and early mortality (2). Exercise is a common weight loss strategy with a prevalence rate of 65% among those attempting to decrease body weight (3). However, reductions in body weight from exercise training are often less than expected due to a variety of compensatory mechanisms (4). These compensatory mechanisms function to either increase energy intake or reduce energy expenditure to maintain energy balance when the body is presented with an energy deficit (5, 6).

Adaptations that decrease metabolic energy expenditure (both at rest and during physical activity) are important aspects of the overall compensatory response (7, 8). Importantly, these reductions in resting and total energy expenditure are mass-independent, expressed as kcal/kg of fat free mass/24 hours, and can total 120 kcal/day (9). These adaptations, which initially present after an individual sustains an energy deficit for about 10 days, functions to return the body back to energy balance, conserving energy to ensure the needs of vital organs are met and resisting further weight loss (8, 10, 11). Indeed, these metabolic adaptations (or metabolic compensation, MC) were once a desirable trait as a survival mechanism in times of food shortage. In today's obesogenic society, however, MC is detracting from desired weight loss and weight loss maintenance (8).

Problem Statement

Metabolic adaptations reduce resting and non-resting energy expenditure in an effort to resist weight loss and/or regain lost weight through mechanisms centered around skeletal muscle metabolism (7, 9, 12, 13). Reductions in skeletal muscle glycolytic activity appear to play a major role in improving skeletal muscle contractile efficiency to reduce the energy cost of physical activity (11). Weight loss also alters thyroid hormone levels, which perturb the relative volume of muscle fiber types (14, 15). Of particular importance is the change in proportions of fast-twitch (type II, primarily glycolytic) vs. slow-twitch (type I, primarily oxidative) (16). Type I muscle fibers consume less energy and generate less power than type II muscle fibers while relying heavily on fatty-acid oxidation (7, 17). In contrast, type II muscle fibers rely heavily on glucose oxidation and are much less efficient than type I (i.e. expend more energy per L of oxygen) (18). Greater circulating thyroid hormone (triiodothyronine) increases skeletal muscle glycolytic activity while a decrease in circulating levels can decrease muscle fiber recruitment favoring slow-twitch fibers in an effort to increase skeletal muscle efficiency (and decrease energy expenditure) at a reduced body weight (15, 19).

Many exercise protocols call for moderate aerobic exercise interventions that result in greater fatty acid oxidation capacities. This protocol could actually promote MC and weight loss resistance as this type of training may augment the declines in glycolytic capacity observed with weight loss (11, 20, 21). An intervention that can increase, or at least maintain, skeletal muscle glucose utilization during weight loss would be expected to attenuate MC and thus be a valuable addition to weight loss interventions. An alternative exercise modality that has gained recent attention is maximal strength training (MST). MST is a particular form of strength training performed at greater, anaerobic, intensities using fast movements in the concentric phase and a high load (80-90% 1-rep max) performed until failure/fatigue. This anaerobic (high intensity) training is known to rely on type II skeletal muscle fibers, forcing glucose utilization to cause reciprocal increases in glycolytic enzyme activity (22, 23, 24). According to this logic, if MST is undertaken during a weight loss program (energy restriction) glycolytic capacity would be maintained and MC attenuated, resulting in greater weight loss or weight loss maintenance (25). The first step, and focus of the present trial, is to determine if MST influences the components of MC (resting and non-resting energy expenditure).

Research Questions

1.) Does MST decrease skeletal muscle work efficiency?

2.) Does MST increase resting energy expenditure (kcal/kg of body weight) ?

3.) Will MST prove to be safe and attainable for this population?

Hypothesis

We hypothesized that an 8-week MST intervention where adults classified as obese who participated in three weekly MST sessions on non-consecutive days would result in greater resting energy expenditure (REE, in kcal/kg FFM) and reduced skeletal muscle efficiency (SME,) indicative of greater energy expenditure of physical activity at a set intensity. We also aimed to demonstrate the feasibility of our MST intervention among sedentary adults classified as obese to illustrate that our intervention would be safe and acceptable for a larger randomized controlled trial. If successful in our aims, this pilot trial would set the stage for future obesity treatment and prevention strategies aimed at combatting MC with MST. The aim of the current study was not to reduce body weight, but rather evaluate MST as a safe and effective intervention that may be used to increase REE and decrease SME (the prime components of MC). Demonstrating that MST is effective at increasing REE and/or decreasing SME would provide justification for its use in a weight loss program to attenuate MC and improve weight loss outcomes.

Chapter Two: Literature Review

Introduction

Over 70% of U.S. adults are classified as either overweight (Body Mass Index (BMI) = 25-29.9) or obese (BMI > 30) (1). Obesity is a major risk factor for the development of type 2 diabetes mellitus (T2DM), pre-diabetes (PD), cardiovascular disease (CVD), coronary artery disease (CA) and early mortality (2). Weight loss and weigh loss management have been shown to be a clinically safe and an effective strategy in the prevention of these comorbidities. To date, diet and aerobic exercise are the primary prescriptions for prevention of weight regain. Exercise is the most common weight loss strategy with a prevalence rate of 65% among those attempting to decrease body weight (3). However, reductions in body weight from exercise training are often less than expected due to metabolic adaptations working to maintain energy balance.

These metabolic adaptations begin to present when an individual has sustained a negative energy balance (~ 10 days or more) (8, 11). Specifically, reductions in resting and total energy expenditure per unit of fat free mass occur to maintain energy homeostasis, conserving energy to ensure the needs of vital organs are met (10). Metabolic adaptations are considered an important, automatic compensatory response in place to resist further weight loss. This compensatory response (or metabolic compensation, MC) was once a desirable trait as a survival mechanism in times of food shortage. In today's obesogenic society, however, MC is detracting from weight loss and weight loss by reduce resting and non-resting energy expenditure to account for approximately 120 kcal/day through mechanisms related to thyroid function, skeletal muscle glucose oxidation, and sympathetic nervous system activity (7, 8).

Skeletal muscle is a prime player in MC. Weight loss reduces muscle glycolytic activity, reducing the energy expenditure of light-intensity activities. In brief, the skeletal muscle of an individual in a sustained negative energy balance has adapted to ensure glycogen is spared for survival, as a result of this sparing, the skeletal muscle has become more efficient (11).

The purpose of this review is to examine the success and failures of previous and current diet induced weight loss management protocols, to elucidate why MC occurs when an individual has sustained a negative energy balance, pinpoint what an individual can do to fight against MC, and if aerobic exercise (AE) or strength training (ST) exercise can offset MC. Finally, if ST exercise can be successful in combatting MC, what is the dose requirement to be efficacious.

Metabolic Compensation

MC was initially coined, "adaptive thermogenesis" (AT) by Ancel Keys and colleagues at The University of Minnesota over seven decades ago during the Minnesota Starvation Experiment. Keys discovered that participants in the study presented a significantly large decline in resting energy expenditure (REE) in comparison to body mass following six months of extreme energy restriction (26, 27).

Today AT is widely accepted as a "counter-regulatory metabolic response that serves to mitigate changes in body weight during periods of energy imbalance (26)." This metabolic response was seen front and center in a 2017 New York Times article highlighting the weight regain of fourteen participants on the hit NBC Television show, *The Biggest Loser*. Contestants on the show suffered from a "slowed metabolism" or MC and the majority of participants saw a recidivism of all weight lost at six years post. The few participants that were able to keep the weight off were meticulous in counting calories and were diligent in tracking daily energy expenditure (EE)(28).

Resting Energy Expenditure

Resting Energy Expenditure (REE) is estimated to account for 60-75% of the calories an individual burns during a day (29, 30). The amount of REE expelled is dependent on a variety of factors, the prime driver of REE increase is a greater amount of skeletal muscle. Thus, the more skeletal muscle an individual has the greater the REE. The gold standard of REE measurement is via indirect calorimetry for a brief interval (25-50 minutes) typically in the morning during the fasted state. The results are then inferred to 24-hour energy production (31). Today, numerous companies (Bodyspec, DexaFit, KORR) and Universities offer RMR services in which an individual can have a low-cost and accurate test to measure expenditure. However, the majority of individuals who are attempting weight loss utilize apps (MyFitnessPal, Lose It, MyNetDiary) that give an estimate for daily energy consumption using the Mifflin St. Jeor equations to estimate EE. While the Mifflin equation does a serviceable job in estimating expenditure using height, weight, gender and age, it is inherently flawed (32). The majority of users who download a nutrition tracking app enter the weight loss journey seeking immediate results. They are inclined to cut calories quickly which has the potential to create a situation in which they are battling MC within the first week of their weight loss mission.

Energy Consumption

Food companies in the United States are permitted to use any of the five different approved methods to calculate nutritional facts on packaging (33). This discrepancy in method allows inaccuracies in labels that can be within +/- 20% (33). This error variability could lead individuals who are "counting calories" to either underestimate consumption or overestimate. In a study titled, *Food Label Accuracy of Common Snack Foods* Jumpertz and colleagues tested 24 of the most common popular snack foods on the U.S. market to assess label accuracy for energy and macronutrient content (34). Using Bomb calorimetry (35) and food factors, which were calculated based on macronutrient weights as reported on the food labels, the team used specific heats of combustion (fat: 9.4 kcal/g, carbohydrate 4.1, protein 5.65) to validate labeling.

Their findings indicated that indeed the most commonly consumed snacks on the U.S. market are, “overall slightly higher than stated on the nutritional label.” Furthermore, research has shown that “energy-dense savory snack food products are preferentially chosen by overweight and obese pre-pubertal children.” These vulnerable children are already at risk for obesity related comorbidities later in life and the relationship with savory snack foods during an impressionable age has the potential to set them up for a lifelong battle with AT (36). Rolls *et al.* examined the effect the portion size of a snack food had on energy intake and certainly it appears that the portion size of a snack can lead an individual to overconsume food (37). Additionally noted in Jumpertz’s study was the finding that 40% of the energy not accounted for on food labels was from carbohydrates (34). This finding has a host of implications long-term in regard to obesity, insulin resistance, T2DM, and adipose tissue storage (38).

While a 2016 Pew Research Study found that most Americans consider their future health to be within their own control for management, 58% said they should “probably eat healthier” most days. 72% of Americans believe that healthy eating habits and getting enough physical exercise are “very important for improving a person’s chances of living a long and healthy life (39).” Yet, the United States is an obesogenic society. Americans know what they should be doing to achieve a long and healthy life span, yet they do not do it. Some have argued that our unhealthy food choices, our inability to not do what we know we should do, is a direct result of the power of advertising. Harris *et al.* showed that food advertising can increase the consumption of unhealthy products, not seen in the advertisements. The influence of advertising was not related to the level of hunger the participant was feeling. Certainly it seems that the power of food advertising is in its ability to ignite automatic eating behaviors which are separate from the brand being advertised (40), of particular concern is the finding that children consume 45% more food following a bout of exposure to advertising.

Energy Deficit Challenges

Nearly 50% of Americans indicate that they are attempting to lose weight (1), and of those who are ultimately successful in shedding excess body weight, 80% will not maintain the weight lost at twelve months post. A meta-analysis by Hall and colleagues revealed that dieters, on average, will regain more than half of what they lose within two years (41). Undoubtedly it seems that factors inside and outside of an individual's control can conspire to inhibit weight loss and encourage weight regain. These factors are biological (MC), behavioral and environmental (41).

The Academy of Dietetics and Nutrition (AND), the world's largest organization of food and nutrition professionals, in 2016 acknowledged that it will require a multi-factor systems approach, socioecological model, to help an individual maintain weight loss long-term. The socioecological model of obesity intervention, which is a framework, proposes multiple levels of influence that when combined together, can positively influence the creation of a negative energy-balance. The various levels include intrapersonal, community, organizational, government and public policy. To achieve sustained weight-loss and management this multi-layered approach has been shown to be the most effective, as one single level is usually insufficient for long-term results (42). The long-term maintenance of weight loss is the primary challenge of obesity treatment (41). If an individual classified as obese is able to maintain weight loss of 3-5% of their body weight this achievement has a host of health improvements coming in the form of reductions in triglycerides, blood glucose and the risk of developing type 2 diabetes. If the same individual can achieve and maintain even greater weight loss (5-10%) the potential for reductions in risk of CVD (LDL, HDL & blood pressure) are increased and these weight reduction milestones diminish the need for the potential of medication for type 2 diabetes (42).

A predominant number of nutritional experts recommend gradual or slow weight loss (SW) for safety reasons due to concerns that rapid weight loss (RW) could cause health side effects (eating disorders, MC, hormone level reductions) (43, 44, 45). However, from a weight loss standpoint RW (severe calorie restriction) vs. SW (moderate calorie restriction negative 400/day) have yielded similar results (43). In a 2016 double-blinded study, 42 either overweight or obese participants were enrolled in either a RW group, prescribed an energy deficit of (1000-1500 kcal/day) or a SW group, prescribed (500-750kcal/day) both groups were prescribed a diet consisting of 15% protein, 30-35% fat and 50-55% carbs. The aim of the researchers was a total of 5% weight loss for participants in either 5 weeks for RW or 15 weeks for SW. The research team found that weight loss was statistically the same for both groups. A significant reduction in waist, hip circumference, body fat and body fat percentage, was observed in the SW group compared to the RW group. The RW group on the other hand saw a reduction in lean mass, fat free mass and REE when compared to the SW group. Triglyceride and VLDL decreased in both groups and the RW group saw a significant decrease in LDL, fasting blood sugar and total cholesterol. In brief, long-term weight loss success appears to favor slow weight loss in yielding better results in BF reduction and without detrimental metabolic side effects. Specifically, reduction in REE and lean mass (43).

The position of AND, is that in situations in which an individual is classified as obese a low-calorie diet (LCD) can be prescribed (46). LCD is usually greater than 800 kcal/day and typically ranges between 1,200-1,600 kcal/day. An individual following this diet would consume meal replacement in the form of shakes or bars in order to provide tangible amounts of energy and macronutrients. The increased structure has been shown to assist in gaining LCD compliance and helps to mitigate any potential issues with portion size or control. Meal replacements assist in limiting dietary variety and provide a convenience factor that helps an individual maintain regimented control over energy consumption (42). In 2011 researchers put 50 overweight or obese individuals on a very low-calorie diet (VLCD) 500 kcal/day for 10-weeks, the diet consisted of the previously mentioned meal replacement shakes and vegetables. While the participants lost a significant amount of weight (13 kg) during the intervention, researchers found the weight loss was not without consequences. Upon completion of the intervention blood samples revealed significant reductions in levels of leptin, peptide YY, cholecystokinin, insulin and amylin and increases in levels of ghrelin, gastric inhibitory polypeptide, and pancreatic polypeptide. One year post initial weight reduction the participants steadily gained back half of the weight lost even when provided with literature and counseling regarding healthy eating and exercise. While leptin and ghrelin levels did begin to show signs of stabilization, following the acute caloric restriction effect, they were still altered as leptin was reduced and ghrelin had increase a year later. As the authors note, “long-term strategies to counteract this change may be needed to prevent obesity relapse (47).” Indeed, it would seem that MC was in full force for these participants.

While today numerous diets and weight loss programs exist (Atkins, Weight Watchers, Keto) for the purpose of this review the focus will be on three (Intermittent Fasting (IF), Paleolithic (PAL) and Mediterranean (MED)) of the most popular in today’s diet culture. Intermittent fasting (IF) has many different methods (5:2,16:8) the 5:2 method has gained the greatest following, 5:2 follows normal energy intake 5 days a week and reduced energy intake (500-600 kcal) 2 days a week. The Paleo (PAL) diet is a lifestyle diet that is modeled after the diet thought to be followed by our hunter & gather ancestors. PAL focuses on animal protein as the main source of fuel, a small amount of fat (nuts & seeds) while eliminating grains, legumes, dairy and processed carbs or sugar. MED has seen its popularity grow in part due to nutritional recommendations by healthcare professionals and Blue Zone discovery (48). The diet prioritizes olive oil, whole grains, fruits, vegetables, fish and encourages a small amount of red meat consumption. Additionally, MED seeks to eliminate processed foods and sugar. When given the choice of one of the three mentioned diets, researchers have found IF to be the most popular and effective (body composition) among those seeking weight loss. However, when it comes to adherence to the diet of choice, MED yielded the greatest compliance. PAL saw the lowest level of compliance and poorest results in weight loss, while IF saw the lowest Diet Quality score presumably due to the lack of restriction on types of food choices (49).

Additional research on IF is demonstrating that a deliberate and planned interruption to IF which is cyclical, may help to reduce the compensatory metabolic response of MC and as a result, improve long term weight loss efficacy (50). The MATADOR (Minimizing Adaptive Thermogenesis And Deactivating Obesity Rebound) study showed that the creation of an alternating two-week period of IF, followed by a “refeeding” or “rest” from calorie restriction every two weeks (2 weeks at 67% energy needs/ 2 weeks at 100%) was sufficient in minimizing MC. REE reduction in the cycled IF group was significantly lower than the group that stayed on IF for the duration of the study, those that cycled and refed also saw a greater reduction in FM (50). It is possible that a cyclical two-week rest period is enough to counteract the AT survival mechanism.

A new body of research is indicating that perhaps when it comes to breaking the barrier of MC for sustained weight loss, it is less about a specific diet and more about macronutrient levels (51). These new findings point towards protein as a major driver in staving off MC during weight maintenance. Obese prediabetic participants were placed on either a moderate (15%) or high (25%) protein diet over the course of a three-year period. Those on the high protein diet were able to counteract MC seen in REE being as predicted, whereas the moderate protein diet was not and saw a reduction in REE below predicted, indicating MC was at play (51). In a systematic review of protein intake and thermogenesis, Halton was direct in his findings stating, “There is convincing evidence that a higher protein intake increases thermogenesis and satiety compared to diets of lower protein content. The weight of evidence also suggests that high protein meals lead to a reduced subsequent energy intake (52).”

Skeletal Muscle Efficiency and Low Intensity Daily Life Activities

As previously discussed, maintenance of a reduced body weight is a multi-factorial challenge for an individual fighting MC. The battle against MC as a barrier to long-term weight loss has been shown at the level of skeletal muscle. When an individual is living at a reduced body weight, the weight that the body has become accustomed to, survival mechanisms seem to present. A body of research from Rosenbaum *et al.* suggests that at a reduced body weight a decrease in energy expended during physical activity, which is the amount of energy expended across 24-h excluding REE and the energy cost of digestion, will result in an increase in skeletal muscle efficiency (7).

In the clinical research setting, skeletal muscle work efficiency has previously been defined, as power generated (Watts converted to kcal/min) /energy expenditure above resting energy expenditure (in kcal/min) at a given level of power or work during cycle ergometry (7). Skeletal muscle efficiency represents an important component to MC, as previously noted, any reduction in skeletal muscle or lean mass following weight loss has major implications on overall REE (7). Aside from the increase of skeletal muscle efficiency following weight loss it also seems that a change in fuel utilization is a potent driver in MC, that is, the skeletal muscles of a reduced body weight will be more efficient at fuel utilization and will be relying less on glycolytic type II fibers to fuel the working muscles. This change is indicative of an increase in the ratio of fatty acid oxidative type I skeletal muscle fibers following weight loss with a reduction in glycolytic type II fibers. However, this change has not been observed when the fibers were examined via histochemical staining (11).

It may very well be that the changes in muscle substrate preference at low levels of work could reflect the body shifting into survival mode and sparing glycogen for long-term survival needs. Conversely, weight change does not alter the circulating concentrations of glucose, the amount of intramuscular glycogen or enzyme activity facilitating glycogenolysis. In short, it seems that weight loss does not alter the availability of glucose, rather the body chooses not to utilize glucose as fuel at low intensities. At a very low power output (10W) the ratio of glycolytic to oxidative enzyme activity ratio, specifically Phosphofructokinase (PFK)/ Cytochrome C Oxidase (COX) in the vastus lateralis muscle, were significantly correlated to skeletal muscle efficiency (11). This change at low power output could have implications for an individual during low intensity daily life activities (walking the dog, cleaning)

Exercise as a Therapy for Metabolic Compensation

As previously noted, exercise is currently the most popular form of treatment for those attempting weight loss or weight loss maintenance with two-thirds of individuals reporting exercise as the choice of therapy (3). In the aftermath of the COVID-19 pandemic the choice of modality for exercise has never been greater with a wide range of physical activity options at the fingertips of most individuals seeking weight loss. These modalities range from traditional aerobic or strength training protocols to more modern HIIT, group fitness or at home routines supported by integrated equipment technology (53).

Aerobic Exercise

The majority of nationally accredited personal training companies prescribe aerobic exercise (AE), that is of the low intensity cardiovascular variety (brisk walking, swimming, jogging, cycling). Stating that, “walking and other moderate-intensity activities can help you maintain a healthy weight and produce many other health-improving outcomes (54).” Further recent research indicates that aerobic exercise alone can result in “clinically significant weight loss for men and women (55).” The success of an AE prescription has been achieved at a dose of either 400 or 600 kcal burned per session, five days a week. Furthermore, it is important to acknowledge that the ten-month study did not manipulate the diet of the participants, which could indicate that the extra energy expenditure from AE is enough to help maintain weight loss (55, 56, 57).

While REE accounts for approximately 60% of daily expenditure, physical activity is estimated to account for about one-third of energy expended during the course of the day (29). The additional energy expended from low intensity physical activity can certainly help contribute to a negative energy balance. Additionally, AE provides long-term health benefits not necessarily associated with weight loss: improved cardiovascular conditioning, decreased risk of heart disease, lowering of blood pressure, increase in HDL cholesterol and a decrease in resting heart rate (58).

The U.S. Department of Health and Human Services recommends the following for “substantial health benefits”: at least 150 minutes to 300 minutes a week of moderate-intensity activity or 75 minutes to 150 minutes of vigorous-intensity aerobic activity on a weekly basis. Adults are also encouraged to participate in muscle-strengthening activities of moderate or greater intensity involving all major muscle groups two or more days a week for additional health benefits (1). Indeed, research does support the belief that moderate-intensity exercise long-term can promote weight loss maintenance in sedentary individuals classified as obese (59).

Strength Training

As previously discussed, evidence supports that skeletal muscle is the prime driver in REE and may act as a combatant against MC (10). Research signifies that skeletal muscle is responsible for up to 40% of an individuals' total body weight, and that muscle mass development may not only stave off metabolic risk factors but also contribute to blunting the effects of aging and loss of muscle mass (60). It is has been well documented that strength training (ST) performed regularly and at an intensity sufficient to stimulate skeletal muscle will result in hypertrophy (61). Following the U.S. Department of Health guidelines, it is understood that 1 to 3 sets of 8 to 12 repetitions per set, at an intensity between 60-70% of an individual’s one repetition maximum (1RM) that is the maximum load that could be lifted for one repetition and completing 8 to 10 exercise per session at 2 to 3 sessions per week, “are likely to be beneficial for maximizing the health effects of increased skeletal muscle mass (60).” Strong emerging literature suggests that ST could potentially be as beneficial as aerobic exercise at reducing cardiometabolic risk factors and could additionally be effective at reducing FM, improving body composition, and increasing skeletal muscle (62).

An additional benefit for ST is its ability to mobilize visceral and subcutaneous adipose tissue in the abdominal region (62), a known predictor of early comorbidities. Furthermore, support exists to indicate that ST can decrease glycosylated hemoglobin levels in individuals with irregular glucose levels and early metabolic disease, while also improving lipoprotein-lipid profiles (60, 63). Current research denotes that, for low-readiness individuals or those with chronic diseases, a single set program could potentially be the most efficacious (64). This single set program encourages the individual to perform one set of 8 to 10 different exercises, working multiple muscle groups, with each exercise performed at up to 15 repetitions of 1RM per workout, two days a week. The recommendation of a single set program is based in part that the workouts require less of a time commitment, could potentially be more cost efficient and as a result could lead to a greater rate of compliance among this population.

Muscle Glucose Oxidation

An alternative exercise modality that has gained recent attention is maximal strength training (MST). MST is a particular form of strength training performed at greater, anaerobic, intensities using fast movements in the concentric phase and a high load (80-90% 1RM) to failure/fatigue which is known to target type II (glucose oxidizing) skeletal muscle fibers (22, 23, 65). Pushing the muscle to fatigue (or failure) has been emphasized as a key modulator for metabolic and strength gains by maximizing activation of motor units and the resulting force output (66). The higher intensity of MST, than that of ST previously discussed, is the key driver behind glucose oxidation of skeletal muscle. The anaerobic intensity of this modality is designed to force glucose oxidation and may lead to improvements in glucose utilization. These improvements could potentially be reflected in a lower skeletal muscle work efficiency, greater resting energy expenditure and greater respiratory quotient (RQ, indicative of greater glucose oxidation) (7).

An additional benefit of MST is that it can be prescribed following the same protocol previously conferred in which an individual completes one single set to failure. This could produce the greatest return on investment by not only limiting the time and cost commitment, but additionally in the creation of excess post-exercise oxygen consumption (EPOC). In brief, EPOC is an elevation in metabolism during recovery from a bout of exercise. While current research results in examining EPOC have varied and wide ranging in measurement of metabolic elevation, it is now apparent that EPOC can occur for 3-24 hours post exercise. The amount of oxygen cost is minimal at 5-13%, however this small increase could hypothetically assist in overcoming the barrier that is MC (67, 68).

Gaps in Literature

It has now been well-established that diet induced weight loss in combination with an exercise program is significantly more effective for long-term weight loss maintenance than diet alone (69). This is in part due to the increase in energy expenditure from the exercise program to counterbalance the impact of MC. Furthermore, while research indicates that both ST and AE are helpful in weight loss maintenance and reduction in FM, it appears that ST may be more efficacious than AE since it has been shown to maintain skeletal muscle and potentially increase muscle mass during weight loss (69). However, to date no study has examined the long-term effectiveness of exercise and weight loss on MC past 18-36 months. While it can be assumed that an individual could continue to stave off or minimize AT if results are seen at 36 months it is possible that the body could adapt to the stimulus and once again return to survival mode. Moreover, for an individual at a greater body weight with a higher level of FM to lose the time requirement will be longer and as a result metabolic compensation could begin to present sooner than in an individual at a lower body weight. While it has been well documented that both AE and anaerobic (MST) exercise can help improve CV risk, more research is required to determine if one is more potent than the other (70).

Although a body of evidence is mounting (22, 25) regarding the ability of maximal strength training to help upregulate glycolytic skeletal muscle activity and offset MC, the current literature has only examined interventions of the (8-12) week variety. Further research is needed to investigate if MST has a rate limiting factor in type II fiber development and if so, does this attenuate or increase the likelihood of an MC occurrence. Aside from the necessity of research examining long-term MST interventions, research that investigates the compliance, safety and enjoyment of MST will also be important for future prescriptions. As previously discussed, AE is the most popular entry point for the low-readiness population as it has been shown to be a low-entry modality into exercise training (71, 72). Since AE involves energy expenditure at a lower intensity and involves body weight or minimal equipment it is generally perceived as the safest modality (73, 74). This safety and ease of entry into a new routine are believed to be strong predictors of long-term compliance (75, 76, 77). Moving forward ST research should focus on qualitative assessments, via surveys, that examine behavior change to ensure ST or MST can create the same level of compliance as AE.

Future studies should also examine the long-term effects of an increase in skeletal muscle efficiency due to weight loss without an exercise intervention. It will be important to learn if skeletal muscle efficiency continues to increase or if skeletal muscle efficiency levels off at a certain time point. Moreover, research examining the role a specific diet (high protein, IF, MATADOR) can play in long-term attenuation of MC will be vital; as many individuals are unable to exercise due to a time budget, income, physical limitations, or a general unwillingness to participate in an exercise program.

Conclusion

When an individual has sustained a negative energy balance for ten or more days, metabolic changes occur (11). These changes present due to metabolic compensation and can result in reduced resting metabolic rate, increase in skeletal muscle efficiency and a decrease in skeletal muscle mass. Furthermore, research has revealed that 95% of individuals following a weight loss diet regain lost weight within one to five years, with two-thirds gaining more weight than they lost while dieting (78). The U.S. Department of Health and Human Services has prescribed a robust exercise protocol aimed at decreasing the rising rates of nationwide obesity in an effort to reduce the comorbidities associated with the classification (71). While the strong body of research discussed shows the positive effect exercise, specifically of the aerobic and moderate strength training variety, can have on helping to increase daily energy expenditure and skeletal muscle, novel prescriptions and long-term studies are needed to validate the impact on long-term MC. MST has been shown to be effective in the upregulation of glycolytic and type II muscle fibers and has the potential to be an efficacious dose for tempering MC, increasing, or maintaining REE and increasing skeletal muscle mass. Additionally, the single set protocol, if shown to be safe and attainable for the population, could be ideal for individuals classified as either overweight or obese on a time and monetary budget.

Chapter Three: MATERIALS & METHODS

Subjects

This trial was a small, internally funded pilot project. A total of 5 participants (2 female, 3 male) were recruited. All participants were classified as obese (BMI 30–45 kg/m^2), aged 18-35 years, and native to the greater Lexington, KY area. All participants self-reported as sedentary (i.e. not engaging in an exercise program at the time of enrollment), not engaging in weight loss activities, nor could have lost or gained over 5% of their current body weight in the previous 12-months. Eligible participants were required to be (1) free of any cardiac, pulmonary, or metabolic health conditions (i.e. diabetes, heart disease, COPD), (2) able to safely engage in exercise, and (3) not taking any medications or dietary supplements which may have influenced energy expenditure or intake. Ability to safely participate in exercise was determined using Health History and Physical Activity Readiness Questionnaires (PAR-Q) (79). Participants were recruited from community settings in the greater Lexington, KY area using a combination of print and online media methods directed by the University of Kentucky's Center for Clinical and Translational Science (CCTS). All study activities were conducted at the University of Kentucky CCTS, UK Performance Nutrition and Body Composition Laboratory (Department of Dietetics and Human Nutrition), and the Human Performance Laboratory, all located on the University of Kentucky (UK) campus. The study was approved by the UK Institutional Review Board. Written informed consent was obtained by all participants prior to enrollment.

Protocol & Design

General Study Protocol. Eligible participants were enrolled in a quasi-experimental intervention, all participating in the same 8-week MST exercise intervention. Participants were instructed not to engage in any exercise outside of the intervention and to refrain from altering current dietary behaviors while enrolled in the study.

Testing

Initial baseline assessments began the week of 9/21/20 and were taken again post intervention starting the week of 12/1/20. All post-intervention assessments were executed 48-72 hours following the final exercise session.

Resting Energy Expenditure (REE). Subjects completed a 30-minute assessment for resting energy expenditure in the fasted state (12 hours) between 7 and 9am. A ventilated canopy was used to collect expired O_2 and CO_2 and analyzed by indirect calorimetry (Quark RMR, Cosmed USA, Chicago). Substrate oxidation (RQ) was calculated as CO_2 expired / O_2 consumed. The Weir equation was used to calculate REE (kcal/24 hrs) (80), which was further adjusted for fat-free mass (FFM).

Body Composition. Kg of fat mass (FM) and FFM was assessed in the fasted state via air displacement plethysmography (BodPod, Cosmed USA, Chicago) immediately following all REE assessments. BodPod data was used to normalize resting and activity-induced energy expenditure to FFM. Body composition changes were not anticipated since participants were enrolled in an 8-week intervention aimed at increasing REE and decreasing SME while not manipulating dietary energy intake.

Skeletal Muscle Work Efficiency (SME). Upon completion of RMR and BodPod assessments, participants were escorted to CCTS for SME testing. Briefly, participants completed a graded exercise cycle ergometer test to measure SME in the fasted state. Subjects cycled between 60 and 80 rpm against graded resistance to generate 10 W, 25 W, 50 W, and 100 W of power in successive 5-minute intervals using a Monark 828E cycle ergometer (Monark Sports & Medical, Vansbro, Sweden). The average rate of energy expenditure and RQ analyzed via Indirect calorimetry (Vyaire Vmax Encore indirect calorimetry system) and recorded as the average for the final minute of each stage. Energy expended per minute was calculated by the Weir equation (81) and normalized to FFM. Following the protocol implemented by Rosenbaum and colleagues (7, 11) SME was expressed as gross mechanical efficiency (GME) calculated as: work (watts converted to kcal/min) / (energy expended (kcal/kg FFM/min) - resting energy expenditure (kcal/FFM/min)) (11).

Isokinetic Strength Test (IST). 24-48-hours after RMR, BodPod and SME baseline assessments, participants completed a pre-exercise intervention Isokinetic Strength Test (IST). Muscle function (peak torque) of the primary knee joint was assessed using an Isokinetic Dynamometer System 4 Pro (Biodex Medical Systems, Inc., Shirley, NY USA) at the University of Kentucky's Human Performance Laboratory. Following a 5-minute warm up of fast walking (3mph), participants were instructed to move their knee joints from 0° to 90° and to perform 10 maximal force repetitions. Immediately following IST participants received a 15-minute equipment orientation to ensure they had an introductory understanding of the exercise space and physical familiarity of the exercise movement patterns that what would be required upon initiation of MST sessions.

8-week MST Exercise Intervention. 72-96 hours after completing all baseline assessments and MST orientation, participants began the 8-week exercise intervention, performing 3 weekly sessions of MST on non-consecutive days under the supervision of a certified National Council of Strength & Fitness (NCSF) personal trainer (PT). Prior to intervention commencement, the PT was trained by the study's Principal Investigator on the required execution of the study protocol. During sessions the PT provided verbal motivation to participants to ensure exercises were performed at the necessary protocol intensity. All sessions were performed individually on Keiser (Keiser, Fresno, CA) high resistance testing and training machines located in the Human Performance Laboratory. A single-set protocol effective for increasing strength and improving pre-diabetes outcomes in both elderly and overweight sedentary individuals without increasing fatty-acid oxidative capacities was used (22, 63). The protocol prescription involved four lower body exercises and two upper body exercises. Lower body exercises consisted of the following

(1) leg press, (2) seated leg extension, (3) seated leg curl, (4) standing squat (A300 squat machine). Upper body exercises included (1) seated chest press and (2) seated pull-down. participants performed one set of each exercise to the point of maximal fatigue/failure (i.e., could not do another repetition) with the goal of performing 6 to 10 repetitions using explosive concentric movements with slow and controlled eccentric movements. Participants worked during each exercise at 80-90% of their one-rep max, determined by the indirect measurement method (65) and adjusted on a session-by-session basis to ensure participants were staying within the 6-10 repetition range throughout the intervention. Participant exercise session adherence was monitored, measured, and recorded by the PT following each session in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Upon completion of the 8-week intervention, participants were assessed for REE, body composition, SME, and IST 48-72 hours after the final MST exercise session.

MST Participant Exit Survey. Following competition of the 8-week intervention participants answered online Exit Survey questionnaire to gage their perceptions regarding the intervention. The survey consisted of seven questions (Table 1), three were open ended and four of which asked participants to rate aspects of the training program on a scale of 1 (very poor) to 5 (very good).

Table 1: Exit Survey Questions

On a scale of 1-5 (1 being the lowest score and 5 being the highest) please rate the following aspects regarding the 8-week exercise intervention you just completed.

Question
Your overall enjoyment in completing the exercise intervention
Your confidence in completing an additional four weeks of the same exercise program
In your opinion, was the exercise program appropriate and attainable for most individuals?
Do you feel more or less confident in making other healthy choices now that you have completed this exercise program? (Example: continue to exercise, eat healthier...)
Would you prefer this type of exercise or more traditional cardio exercise?
What was one thing you particularly appreciated about the exercise program?
Was there anything you would like to change in regard to the exercise program?

Calculations

REE was calculated using the Weir Equation and normalized to fat-free mass while substrate oxidation (RQ) was calculated as (CO_2 expired / O_2 consumed) (80). Indirect calorimetry and the Weir equation was also used to determine energy expenditure during the SME test. Power generated during the SME cycle ergometry test (watts, W) was converted to kilocalories per minute of power generated (1 W = 0.01433 kcal/min). SME is calculated as the ratio of power generated (in kcal/min) divided by energy expended (kcal/min) above REE (kcal/min) (7, 17, 82) at a given level of power generated (10, 25, 50 W or 100 W). Isokinetic Strength Test was expressed as the peak muscular force output at any moment during a repetition (83). Force output is scored via Dynamometer software and is indicative of a muscle's strength capabilities.

Statistical Analyses

The aim of our statistical analyses was to quantify pre-intervention (baseline) to post-intervention percent change in all outcome variables as there was no group factor to include. All data are presented as means ± standard error. Pre and post comparisons were made via one-way ANOVA for each outcome variable (SME, IST, REE, RQ, BF%, FFM, FM). Change scores were calculated as post value minus pre value. Percent changes were tested via single sample *t* test to determine if changes were different from zero and thus indicative of a significant change over time. Paired sample *t* tests were used to compare baseline and post-intervention calculated 1RM for each exercise in the protocol. Statistical significance was set prior as $P \leq 0.05$. Data was analyzed using IBM SPSS Statistics package version 27 (84).

Chapter Four: RESULTS

Baseline mean age and BMI were 26.8 and 34.9 respectfully with no difference between males and females. Table 2 details the pre and post values for all anthropomorphic and energy expenditure outcomes.

Table 2: Anthropomorphic and *Energy Expenditure Outcomes (Resting Energy Expenditure and Skeletal Muscle Work Efficiency) before and after a 8-week MST intervention* $p \leq 0.05$

	Baseline	Post	Change	Cohen's *d*
Weight (kg)	105.54 ± 12.35	107.86 ± 13.51	2.32 ± 1.87	0.08
% Body Fat	40.70 ± 4.66	40.86 ± 4.07	0.16 ± 0.70	0.02
FFM[a]	61.19 ± 5.58	62.71 ± 5.99	1.52 ± 0.86	0.11
FM[b]	43.89 ± 9.12	45.17 ± 9.23	1.28 ± 1.14	0.06
IST[c]	172.58 ± 34.36	184.42 ± 31.86	11.84 ± 11.17	0.16
REE/FFM[d]	30.51 ± 1.83	37.38 ± 1.98	6.87 ± 1.83*	1.61
RQ[e]	0.86 ± 0.05	0.73 ± 0.04	-0.13 ± 0.08	1.35
SME 10W[f]	23.66 ± 2.30	23.93 ± 1.95	0.27 ± 1.67	0.06
SME 25W	49.73 ± 5.03	46.50 ± 3.93	-3.24 ± 3.73	0.32
SME 50W	82.29 ± 9.53	78.98 ± 6.86	-3.30 ± 5.48	0.18
SME 100W	108.56 ± 11.03	115.28 ± 10.42	6.72 ± 7.62	0.28

*Change significantly different from zero (P=0.02)
Data presented as means ± SE
A= kg fat-free mass
B=kg fat mass
C= Isokinetic Strength Test of muscle function (peak torque) of the primary knee joint was assessed using an Isokinetic Dynamometer
D=Resting Energy Expenditure per kg of fat free mass
E=Substrate Oxidation (CO_2 expired / O_2 consumed)
F= Skeletal Muscle Work Efficiency at 10, 25, 50 and 100 Watts calculated as (watts converted to kcal/min) / (energy expended (kcal/kg FFM/min) - resting energy expenditure (kcal/FFM/min))

Effects of MST Intervention on Resting Energy Expenditure

8-weeks of maximal strength training resulted in a 22.48 % increase in REE per kg FFM (*P*=0.02). There were no changes in RQ from baseline to post intervention. No effects of gender were discovered in respects to REE or RQ change.

Effects of MST on Skeletal Muscle Work Efficiency

Changes in SME trended towards significant decreases at 25 W (-6.51%, *P*=0.435) and 50 W (-4.01%, *P*=0.579) mirroring trends seen by Rosenbaum and colleagues (11). SME changed very little at 10 W (1.18%, *P*=0.878) and trended towards an increase 100W (6.19%, P=0.428). No sex effects were discovered regarding SME changes.

Effects of MST Intervention on Body Composition

There were no changes in body weight, fat-free mass, fat mass or percent body fat.

Effects of MST Intervention on Strength

Improvements in isokinetic strength trended towards improvements (6.86%, *P*=0.349). There were no sex effects in regard to isokinetic strength. As depicted in Table 3, 1RM improvements were observed for Leg Curl (*P*=0.03), Leg Extension (*P*=0.01), Squat (*P*=0.04) and Chest Press (P=0.01) exercises.

***Table 3*:** Results of the 1-rep Max Strength Assessment Determined at Baseline and Post Intervention

	Baseline	Post	Change
Leg Press	390.77 ± 93.43	1136.78 ± 118.54	326.68 ± 97.24
Leg Curl	188.00 ± 21.44	305.46 ± 53.61	59.08 ± 15.12*
Leg Extension	189.12 ± 20.68	301.54 ± 55.67	54.04 ± 13.91*
Squat	235.23 ± 51.19	683.28 ± 144.09	198.15 ± 30.04*
Chest Press	168.29 ± 27.16	249.90 ± 57.08	42.71 ± 12.04*
Pulldown	206.54 ± 20.25	286.10 ± 56.42	33.50 ± 16.78

*Pre to post intervention change different from zero ($P<0.05$)
Data presented as means ± SE

Exit Survey

Mean Exit Survey results are presented in Table 4, indicating the MST intervention was received exceptionally well.

Table 4: Results of Exit Survey Questions from Table 1.

	Mean	SD
Overall Enjoyment	4.8	0.45
Confidence in 4-more weeks	4.8	0.45
Program Appropriate	4.6	0.89
Confidence in Other Healthy Choices	3.8	0.45

Survey was on a 5-point scale, 1 being the lowest score and 5 being the highest.

Chapter Five: DISCUSSION

DISCUSSION

The major findings of our MST intervention are that 8-weeks of MST is an effective dose to significantly increase REE and demonstrated trends towards decreasing skeletal muscle work efficiency at 25 and 50W of power. These findings highlight that MST can increase energy expenditure in sedentary adults, classified as obese and thus has the potential to be an efficacious prescription for attenuating MC.

Our study stood on the shoulders of a body of evidence mounted by leading researchers who have demonstrated reductions in skeletal muscle glycolytic activity coincide with weight loss and result in reductions in energy expenditure (at rest or during light physical activity) (8, 19, 85). While Rosenbaum and colleagues demonstrated a 5% increase in SME at 25W for individuals with 10% weight loss (86), we have demonstrated a 6.5% decrease in SME for individuals following our 8-week MST intervention. These findings point to the impact MST can have at offsetting increases in SME.

An individual at a reduced body weight is certainly fighting an uphill battle to sustain or maintain weight loss due to the weight loss-induced decreases in metabolic energy expenditure, leaving them vulnerable to weight recidivism if energy consumption is not monitored closely (7, 8, 10, 11, 87). Indeed, an individual at a reduced body weight expends less energy than a matched individual (height, weight, gender, age, physical activity level) who is weight stable (has never lost weight). In this way, the individual at a reduced body weight will gain weight when consuming the same amount of energy as the individual who is weight stable. In a recent perspective, Kevin Hall revisited the challenges of persistent metabolic adaptation among contestants of the “Biggest Loser” noting that participants who maintained the greatest weight loss also demonstrated the greatest MC (88) as measured via the doubly labeled water method

(89). Thus, an intervention like MST that can attenuate the overall MC response by increasing REE and decreasing SME would be of great importance to future obesity treatment paradigms.

To our knowledge, this is the first intervention to investigate the effects of MST on REE and SME in obese humans. A prior study by Rosenbaum et al. utilizing traditional resistance exercise to counter weight loss-induced increases in SME demonstrated a 10% decrease in SME at 10-25 watts (86). In the present study, changes in SME decreased 6.51% at 25 watts, similar to that of Rosenbaum et al. although not reaching statistical significance likely due to the low sample size (n=5)(86). Importantly, we demonstrate the greatest declines in SME occurred at 25 watts, an intensity commiserate with light physical activity, also in line with Rosenbaum's findings. Since adults spend most of their time at this physical activity intensity (activities of daily living), decreasing SME at this intensity may provide great utility in countering MC. In contrast, we demonstrated trends for greater efficacy at 100W, which is in line with other research demonstrating resistance exercise can improve exercise economy (90, 91) although this was not the intention of this pilot trial.

In the previously discussed Rosenbaum et al. study, changes in glycolytic capacity were not observed following a standard RT protocol. The researchers likely were unable to induce changes since the intensity of that protocol was less than MST. We hypothesize that if the intensity had met the level of MST they would have observed more robust decreases in SME or significant increases in REE (86). While the present study did not assess glycolytic capacity due to budgetary constraints, the decreases in REE and SME observed signals the likelihood that the MST intervention was more effective at targeting and upregulating glycolytic and type II muscle fibers. This is why, despite the small sample size, the present study demonstrated significant increases in REE (16, 92).

Despite our limited sample size, the present trial demonstrated significant changes in REE after only 8-weeks. Our finding of an increase in REE agrees with previous studies investigating resistance exercise and its effect on REE (93, 94, 95, 96, 97, 98). However, a limited number of studies have normalized energy expenditure to FFM. It is well established that an increase in FFM, as a result of resistance exercise, will increase REE (94, 95, 96, 97, 98). For this reason, the present trial, similar to Kirk et. al. (93) quantified REE per unit of FFM.

Improvements in IST, while only trending towards significance, is encouraging. Due to our time and monetary budgetary restraints, we were only able to measure IST of the quadriceps. However, as Wearing *et al.* and Kamiya and colleagues have shown, this muscle is an appropriate predictor of overall strength development and all-cause mortality (99, 100).

While all participants answered 3 out of 5 or greater on all Exit Survey rating questions, the most encouraging discovery were the answers to our open-ended question, *would you prefer this type of exercise or more traditional cardio exercise?* All five subjects expressed that indeed MST was preferred to cardiovascular exercise. MST02 expressed, "I like this type because of the shorter time commitment and the feeling of strength by moving some really heavy things." This finding contradicts the American Council of Exercise (ACE) position that low-readiness individuals should start with moderate intensity cardiovascular exercise and focus on aerobic fitness prior to strength training (54). This single set MST protocol also proved to be safe and attainable for an obese, previously sedentary population as there were zero adverse events during the 8-week intervention that also saw excellent compliance. Four out of the five participants attended all of the 24 sessions and the fifth participant missed only one session.

An important caveat to consider is the present study did not intentionally place participants in an energy deficit to force MC. It is therefore uncertain if MST can attenuate these markers of MC while an individual is in an energy deficit. This will be an important question for future trials.

STRENGTHS & LIMITATIONS

As a preliminary pilot study carried out during a once in a century pandemic, this small investigation was underpowered and may not be indicative of our population as a whole.

However, our sample of 5-subjects is the same number as that of Phinney and colleagues used in a 1983 study that has spawned nearly 40-years of Low Carbohydrate High Fat research for endurance performance (101). Despite this small sample, our MST intervention significantly increased REE, making this a very noteworthy finding and topic for future trials. While not of statistical significance, decreases in SME at 25 W and 50 W were greater than the statistically significant increases demonstrated after 10% weight loss (86). As noted in table 1, the Cohen's d effect size for SME at 25W was moderate at 0.32, giving us confidence that a larger sample size, or potentially a longer intervention, would have produced more robust results. These SME trends highlight the importance of these findings as foundational data for future clinical trials.

As human researchers across the world experienced, the COVID-19 pandemic provided a host of limitations and challenges. We are incredibly grateful to our participants for adjusting to the fluidity of pandemic protocols. Furthermore, we owe a great deal of gratitude to the University of Kentucky for including our study in Phase 1 of research re-opening and for allowing us to safely complete our intervention. As citizens across the world have learned, face masks are a necessary protection in combating COVID-19. However, when it comes to exercise, current literature is mixed on the impact of facial covering requirements on physical exercise performance (102). Since our participants were sedentary and not elite athletes, the additional barrier to normal breathing while exercising at a high intensity could have limited performance. The pandemic additionally caused challenges in the scheduling of MST sessions and testing. To ensure our research was in compliance with social distancing practices, training sessions and testing were forced to occur during limited and at times, varied windows of the day. As a result, the variability in time-of-day sessions could have impacted performance of participants during sessions. However, despite these pandemic related limitations, a major strength of our study was that all participants completed the 8-week intervention safely without injury or illness. Additionally, the strong rating by our participants in regard to "your overall level of enjoyment of the intervention” should not be overlooked and is encouraging for future clinical trials. Compliance, more than any other variable, is the greatest hurdle in long-term weight loss and weight loss maintenance. In this way, the perceived enjoyment of the study participants may have great implications for the long-term efficacy of an MST prescription (103, 104, 105).

FOOTNOTES

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DATA AVAILABILITY

Raw data for the present study can be accessed at 10.6084/m9.figshare.17695259

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VITA

Robert E. Anderson III, BFA

Place of Birth

Louisville, KY

Education

MS University of Kentucky, Nutrition & Food Systems May 2022 (Expected)

BFA Western Kentucky University, Performing Arts: Directing May 2008
Graduated Cum Laude

Honors and Awards

GradResearch Live! 3-Minute Thesis Competition 2021
University of Kentucky, *1st Place*

CCTS Research Days 2021
University of Kentucky, *3rd Place Von Allmen 1-minute Abstract Poster Competition*

Buster Fellowship 2020, 2021
University of Kentucky, School of Human Environmental Sciences

Kilpatrick Fellowship 2022
University of Kentucky, School of Human Environmental Sciences

Omicron Delta Kappa Academic Honorary Society 2022
UK Nu Circle

Publications

Anderson RE, Flack KD. Maximal Strength Training Increases Energy Expenditure in Sedentary Adults Classified as Obese, a pilot study. Journal of Human Nutrition, in review.

Flack KD, **Anderson RE,** McFee K, Rush C. Exercise Increases Attentional Bias Towards Food Cues in Individuals Classified as Overweight to Obese. *Physiology & Behavior*, 113711, 2022.

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