THE EFFECTS OF EXERCISE TRAINING ON RESTING METABOLIC RATE IN YOUTH WITH OVERWEIGHT OR OBESITY

WINNIE WING-YAN YU

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

GRADUATE PROGRAM IN KINESIOLOGY AND HEALTH SCIENCE

YORK UNIVERSITY

TORONTO, CANADA

JULY 2020

Abstract

Resting metabolic rate (RMR) is the largest component in energy expenditure and is often reduced with weight loss. Exercise training has been shown to attenuate RMR reductions in adults. However, little is known about the effects of exercise training and body composition changes on RMR in youth with overweight or obesity. A secondary analysis of sedentary youth (≤18 years, BMI percentile > 85%), randomly assigned to either a control group or one of 3 exercise intervention groups: aerobic, resistance or combined, was conducted. Absolute RMR change did not differ between exercise modalities compared to control. Changes in fat free mass (FFM), but not fat mass, visceral fat or skeletal muscle was significantly associated with changes in RMR independent of exercise modality. Thus, in youth with overweight or obesity, although exercise modality was not associated with different changes in RMR, FFM change appears to be a modest predictor of RMR change.

Acknowledgements

A note of thanks:

Thank you to my parents who have given me unconditional love and support through failures and successes. You have always given me the freedom to chase my dreams no matter how unrealistic it may be and for that, I am eternally grateful. To say the least, you have widen my perspectives, given me the best life advices and have encouraged me to keep going and to trust the process.

Thank you to my wonderful lab mates, Rubin, Sarah, Zahava, Simi, Diana, Arsh, Wally and Maral, who have made the walk up the hill to Sherman much more bearable. From decorating the lab and long lab chats to catching spiders and eating the BEST blondies and brownies, I am grateful to have shared these memories with all of you. Cheers to making the lab a place where the grass is always the greenest! To Dr. SoJung Lee, thank you for letting me use the data collected from your studies, I have learned so much from them. To my committee member, Dr. Hala Tamim, thank you for your constructive feedback and suggestions that further improved my research.

Finally, I would like to express my sincere gratitude and thanks to my supervisor, Dr. Jennifer Kuk. Words cannot describe how grateful I am to be one of your students. Thank you for all the support, guidance and constructive feedback you have given me over the years. You continuously made it a priority to help me discover my strengths and provided me with opportunities to make the most out of my degrees. Thank you for believing and seeing potential in me even when I could not see it myself. It was through your words of encouragement that reminded me of how much I actually know. You are honestly the best and I hope that our paths cross again in the future!

Table of Contents

List of Tables

List of Figures

1.0 General Introduction

The well-established associations between obesity and various negative health consequences [1–3] highlight the importance of childhood obesity as an important public health issue. Resting metabolic rate (RMR) is one of the largest components of daily energy expenditure [4] and is greatly influenced by fat free mass (FFM) [5–7]. However, FFM is often reduced with weight loss and is associated with decreases in RMR [8]. Several studies have examined the effects of exercise training on RMR but are mostly limited to the adult population. In adults, resistance exercise has been shown to increase FFM and RMR when there is no weight loss [9] whereas inconsistent findings are observed in studies examining the effect of aerobic exercise on RMR. Studies have reported aerobic exercise to conserve [10], increase [11] or have no effect on RMR [12,13]. Although exercise training may improve body composition in both adults and youth, youth generally have less muscle mass and may have a different response to exercise than adults. Further, youth are undergoing growth and have a lower skeletal muscle to FFM ratio which may have important implications for RMR. Limited understanding on the effects of different exercise modalities on RMR in youth with overweight or obesity warrants further investigation.

Therefore, this thesis will examine the effects of different exercise modalities on the changes of RMR and whether these changes are related to body composition changes in youth with overweight or obesity.

2.0 Review of Literature

2.1 Introduction

The present literature review will detail current understanding on the potential importance of RMR in weight management and the effects of different exercise modalities on RMR and body composition changes in adults and youth.

2.2 Childhood Obesity: Why is it a problem?

Childhood obesity is a serious public health concerns worldwide [14]. It is estimated that 1 in 5 children and adolescents in the United States currently have obesity [15]. Recently, trends in mean BMI have started to plateau in high-income countries such as Canada and the United States but it continues to remain at high levels [16].

It is well established in the literature that obesity is associated with many health consequences, disease and mortality [1–3]. Children with obesity are also at greater risk of developing cardiovascular diseases (CVD) as adults [17,18], which is currently the leading cause of death [19].

2.3 Weight Management: The prevention and treatment of obesity

The benefits of weight loss are well documented in the literature such as improvements in metabolic profiles [20–22] and CVD risk factors [23]. Health-related quality of life such as physical function and self-esteem are also improved with reductions in weight [24]. Current approaches to managing obesity target lifestyle modifications that include diet and physical activity behaviours [25]. However, long term weight management is challenging and weight regain is common. In general, adults who have lost weight, will regain about one-third of their weight lost in a year and most regain all of their weight within 5 years [26]. A possible contributor to weight regain is the reduction in RMR that often occurs with weight loss. This reduction in RMR is proposed to be a result of the body's acute compensatory response to negative energy balance [27] and chronic responses related to changes in body composition, namely reductions in fat mass (FM) and FFM [8]. Thus, individuals who have lost weight will likely have lower RMR relative to their pre-weight loss state. Given that reductions in RMR decrease total energy expenditure, if efforts are not made to decrease energy intake and/or increase energy expenditure, the accumulation of excess energy may result in weight regain [28]. Thus, this highlights that RMR may be a significant metabolic contributor to weight regain [29] and strategies that limit the reduction in RMR may improve long term weight management.

2.4 Resting Metabolic Rate

Resting metabolic rate (RMR) is the minimum energy required to maintain resting functions of the body representing approximately 60-75% of an individual's total daily energy expenditure [4]. RMR is highly variable between individuals and across the lifespan. Several factors that contribute to this variance include, but are not limited to, age, hormones and body composition [4,7].

Indirect calorimetry is the gold standard measure for energy expenditure and is associated with coefficients of variation ranging between 2 to 7% [30–34]. This may be attributed to normal biological and instrumental variability as well as measurement error [32]. When assessing metabolic rates in youth, it is also important to account for changes in body composition due to growth and development. A systematic review [35] reports a 12% median higher absolute RMR in pubertal versus pre-pubertal youth. However, when expressed relative to FFM, RMR appears to decrease as children mature from Tanner stage 1 to 4 and 5 (ΔRMR: -223 kcal/day) [36]. The researchers attributed the decline in RMR to the disproportional growth of skeletal muscle mass which is less metabolically active compared to internal organs. Thus, it is clear that changes in body composition due to growth greatly contributes to the variability in RMR.

2.5 Exercise Training and Resting Metabolic Rate

Interventions that can improve RMR or attenuate reductions in RMR seen with weight loss may have important implications for long term weight management. Exercise training is known to induce acute elevations in RMR after a bout of exercise, known as excess post-exercise oxygen consumption (EPOC), and chronic changes in RMR due to changes in FFM and FM. To date, several studies have examined the effects of exercise training on RMR [9–11,13], but are mostly limited to the adult population.

<u>Excess Post-Exercise Oxygen Consumption (Acute Effects)</u>

The acute effects of a single bout of exercise on oxygen consumption, also known as EPOC, is typically observed to have two phases: short and long term EPOC [37]. Short-term EPOC occurs immediately after exercise with oxygen consumption at its peak before decreasing rapidly and dissipates within a few minutes to an hour [38,39]. It is then followed by the long-term phase where oxygen consumption progressively decreases until the body returns to its pre-exercise state RMR [37].

After aerobic exercise, the magnitude of long-term EPOC is dependent on the duration and intensity of the exercise bout performed [38]. In resistance exercise, EPOC appears to be associated with the intensity, but not duration of exercise [38]. The EPOC response following resistance exercise is greater than aerobic exercise and may be due to the greater disturbance in one’s hemostasis with resistance exercise such as higher lactate concentration which requires greater oxygen to restore the body [40]. EPOC after a bout of moderate-intensity aerobic exercise is suggested to dissipate by 24 hours [41] whereas for resistance exercise, significant elevations in RMR may be observed up to 72 hours post-exercise [42]. Thus, RMR protocol should be measured 72 hours post-exercise bout to account for the residual effects of EPOC on RMR.

Body Composition Changes (Chronic Effects)

Body composition is the largest contributor to inter-individual variances in RMR such that approximately 70% of the variability can be explained by FFM and FM [7]. In theory, resistance training (RT) has the potential to positively influence RMR given that it is associated with greater increases in FFM than aerobic training (AT) [43,44]. It is unclear whether AT-induced weight loss can also improve RMR. In addition to muscle mass, FFM is comprised of other metabolically active organs and tissues (ie. brain, heart, liver, etc.) as well as non-metabolically active components (ie. bone and extracellular mass) [45]. FM is not as metabolically active as FFM and typically decreases with weight loss. Previous studies have shown that FM only explains a small part of RMR after accounting for FFM [7,46]. Therefore, given the importance of FFM on RMR, interventions that conserve or increase FFM may be more likely to be associated with a maintenance or improvement in RMR.

Changes in Fat Free Mass (FFM)

RT has been proposed to positively influence RMR by increasing muscle mass. Several studies [9,47] have examined the effects of RT on RMR in adults and report significant increases in absolute RMR (ΔRMR: 44 kcal/day to 73 kcal/day). Participants in these studies did not lose weight and significant increases in FFM (1.9 to 2.4 kg) were observed. Stavres et al [48] report an increase in RMR (ΔRMR: 247 kcals/day) after RT even with no changes in FFM or weight.

However, this study did not report the timing of the RMR measures post exercise training, and so whether this increase reflects the acute effects of exercise on RMR or some other cause are unclear. Finally, Miller et al [49] report that participants who lost 3.1 kg of their body weight with a 4 month RT and diet intervention (-632 kcal/day energy restriction), but maintained their FFM, were able to maintain their RMR. Together, these studies provide support that RT in adults, have the potential to conserve or positively influence RMR.

Whether RT positively influences RMR in youth with overweight or obesity is still unclear. Youth generally have less muscle mass than adults and are undergoing growth and development. Thus, in youth with overweight or obesity, RT is not often reported to be associated with greater increases in RMR beyond what is observed in the control groups [50,51]. Treuth et al [50], report both control and RT groups are associated with elevated RMR and increases in FFM as compared to baseline, whereas Alberga et al [51] report no differences in RMR or FFM between the control and RT group.

Aerobic training is generally not associated with increases in muscle mass [52] and is hypothesized to have little impact on RMR. In weight-stable adults, Lee et al [10] report that the AT group conserved their FFM and RMR whereas its control group experienced significant decreases in RMR. However, in studies that report weight loss, changes in RMR may be dependent on the magnitude of weight and FFM loss. Hunter et al [12] observed that AT was unable to conserve RMR with large dietary weight loss (13 kg). Both AT and control groups reported significant reductions in FFM (AT: -1 kg; Control: -1.5 kg) and RMR (AT: -75 kcal/day; Control: -103 kcal/day) relative to baseline. Conversely, Potteiger et al [11] report an increase in RMR (174 kcals/day) with weight loss (-5.2 kg) but no significant changes in FFM in men after AT. Thus, the relationship between AT and RMR is still unclear given that it is generally not associated with improvements in FFM.

To our knowledge, only the HEARTY trial [51] has examined the effect of AT on RMR in youth with overweight or obesity. The researchers found no change in RMR relative to the control group despite significant within-group increases in FFM (0.7 kg). It should be noted that normal growth and development may have contributed to the increase in FFM observed considering that control group also had a 1.1 kg increase in FFM. Therefore, the limited literature on this topic warrants further investigation to determine whether an association exists between AT and changes in RMR, particularly in youth with overweight or obesity.

Changes in Fat Mass (FM)

FM does not appear to be a strong predictor of RMR and accounts for an estimated 6% of the variance in RMR, which is far lower than the 63% variance accounted for by FFM [7]. Further, FM generally has a much lower metabolic activity such that decreases in FM is unlikely to impact RMR.

2.6 Summary of Literature

Overall, it is clear that childhood obesity is a concerning public health issue. RMR has been identified as an important factor for weight management. In adults, RT is associated with the maintenance of RMR with weight loss [49] and the increase in RMR without weight loss [9,47], whereas the effect of AT on RMR may be dependent on whether weight and FFM was lost [11,12]. Whether this relationship is similar in youth is unclear considering that youth have less muscle mass and are undergoing growth and development. Thus, the aim of this study is to examine the effects of aerobic, resistance and combined exercise training on RMR changes without dietary restrictions in youth with overweight or obesity and to determine whether changes in body composition are associated with RMR change in this population.

3.0 Manuscript

The Effects of Exercise Training on Resting Metabolic Rate

in Youth with Overweight or Obesity

Winnie W. Yu[1], SoJung Lee[2], Hala Tamim[1], Jennifer L. Kuk[1]

[1]School of Kinesiology and Health Sciences, York University, Toronto, ON, Canada

[2]Division of Sports Medicine, Graduate School of Physical Education, Kyung Hee University, Yongin, Republic of Korea

3.1 Abstract

Objectives: This study will examine: 1) the effects of aerobic and/or resistance exercise training without dietary restriction on resting metabolic rate (RMR) and 2) whether changes in body composition are associated with changes in RMR in youth with overweight or obesity.

Methods: 140 sedentary boys and girls (≤18 years, BMI percentile > 85%) participating in two previously published trials, were randomly assigned to either a control group (n=18) or one of 3 exercise modalities: aerobic (n=51), resistance (n=50) or a combination of aerobic and resistance (n=21). RMR was measured by indirect calorimetry with a ventilated hood and body composition was measured by DXA and MRI.

Results: Changes in absolute RMR did not differ between different exercise modalities versus control (p>0.05). Significant decreases in fat mass (FM) were observed in the aerobic (-1.9 ± 0.4 kg) and resistance (-1.0 ± 0.4 kg) groups whereas all groups decreased in visceral fat (-0.2 ± 0.02 kg) compared to control. Increase in fat free mass (FFM) was only seen in the combined group (2.3 ± 0.4 kg) whereas increases in skeletal muscle were observed in both resistance (1.2 ± 0.2 kg) and combined (1.5 ± 0.3 kg) groups versus control. Changes in FFM, but not FM, visceral fat or skeletal muscle was a significant determinant of RMR change independent of exercise modality (p=0.04).

Conclusion: Although the type of exercise performed was not associated with different changes in RMR, findings from the study support that changes in FFM is a modest predictor of RMR change in youth with overweight or obesity.

3.2 Introduction

Resting metabolic rate (RMR) is a major component of total energy expenditure, representing the amount of energy required to sustain normal functions of the body at rest [4]. It is also known that fat free mass (FFM) is a strong predictor of RMR in both adults and youth [5,7,53]. As such, interventions that are associated with reductions in FFM such as dietary weight loss are also associated with decreases in RMR [54–56]. Changes in RMR associated with weight loss may potentially have important implications in long term weight management.

Whether exercise weight loss is also associated with reductions in RMR is of particular interest. Increased physical activity is associated with improvements in FFM or maintenance of FFM during weight loss and thus is recommended as a component of weight management behaviour interventions in adults with obesity [25,57]. In adults, resistance exercise is generally associated with increases in FFM and RMR when weight is maintained [9] and RMR is conserved when weight is lost [49]. The relationship between aerobic exercise and RMR, however, is inconclusive and may depend on weight and/or FFM loss [10–13]. Currently, little is known regarding the effects of different exercise modalities on RMR change in youth. Given that youth are also undergoing growth and development and have less absolute muscle mass and a lower muscle mass to total FFM ratio than adults, it is unclear whether exercise training will have a similar effect on RMR as adults.

Thus, the aim of the study is to examine the effects of aerobic, resistance and combined exercise training on the change in RMR without dietary restrictions and to determine whether changes in body composition are related to RMR change in youth with overweight or obesity.

3.3 Methods

Participants

Participants of the study included 140 previously sedentary boys and girls (≤18 years) with a body mass index (BMI) percentile greater than the 85th percentile who participated in one of three previously conducted exercise intervention trials (ClinicalTrials.gov identifier: NCT00739180, NCT01323088, and NCT01938950). Participants were randomly assigned to either a control group or one of 3 exercise modalities: aerobic, resistance or a combination of aerobic and resistance (**Appendix A**). The primary objectives of the intervention trials were to examine the effects of different exercise modalities on visceral adiposity and insulin sensitivity in youth with overweight or obesity. Primary outcomes were conducted from 2007 through to 2017 at the University of Pittsburgh and have been previously reported [58–60]. Participants who completed the exercise intervention and have complete body composition, cardiorespiratory fitness and RMR measurements at baseline and post-intervention were included in this study. Three individuals with extreme changes in RMR (>800 kcal/day (n=2) or <-800 kcal/day (n=1)) were excluded. Final study sample included 85% (140/165) of participants who completed the exercise trials [58–60]. Within each exercise group, 86% (51/59) were included for aerobic exercise, 86% (50/58) were included for resistance exercise and 78% (21/27) were included for combined exercise. Participant and parental consent were obtained prior to the participation of the intervention trials. These trials were approved by the Institutional Review Board at the University of Pittsburgh. Approval to conduct a secondary analysis was obtained from York University's Research Ethics Board.

Diet Intervention

At baseline, all participants attended two nutrition counselling sessions. Individualized caloric intake targets (55-60% carbohydrate, 15-20% protein, and 20-30% fat) that promoted healthy weight maintenance was determined by study dieticians. Participants were asked to follow their respective caloric intake targets throughout the study and adherence was monitored by body weight examination and monthly 24-hour dietary recall interviews.

Exercise Interventions

Details of the three exercise intervention trials have been reported previously [58–60]. Participants in the aerobic group performed three supervised sessions per week on a treadmill, elliptical or bike for 60 minutes at a target of 50–75% VO_{2peak}. Participants in the resistance exercise group used weight machines to complete 2 sets of whole-body exercise three times per week for 60 minutes. In the combination exercise group, participants performed 30 minutes of aerobic exercise and 30 minutes (1 set) of whole-body resistance exercise, three times per week. Duration of the exercise intervention trials was 3 to 6 months. Participants in the control group did not partake in any exercise interventions.

Resting Metabolic Rate (RMR)

RMR measurements were taken during baseline and post-intervention visits. At each visit, participants were admitted overnight to the Pediatric Clinical and Translational Research Center (PCTRC) at the Children's Hospital of Pittsburgh for a 10 to 12 hour overnight fast. After waking, participants were asked to rest in bed for two hours prior to RMR testing. RMR was measured for 30 minutes using a ventilated hood system (Parvo Medics, Salt Lake City, UT). Participants were asked not to move or fidget during the duration of RMR testing. Post-intervention measurements were taken 72 hours after the last exercise session. RMR change is defined as the difference between baseline and post-intervention RMR measurements.

Anthropometrics and Body Composition

Anthropometrics and body composition measurements were taken during each baseline and post-intervention visit. Body weight was measured using a digital scale to the nearest 0.1 kg and height was measured using a stadiometer to the nearest 0.1 cm. Fat mass (FM) and FFM was measured using the Lunar iDXA (GE Healthcare, Madison, Wisconsin). Visceral fat and skeletal muscle were assessed by obtaining whole-body magnetic resonance imaging (MRI) data with a 3.0 Tesla magnet (Siemens Medical Systems, Erlangen, Germany).

Covariates

Baseline participant characteristics analyzed in the study included age, sex, body weight, ethnicity, Tanner stage and BMI. Ethnicity was self-reported by participants. Pubertal development was assessed in accordance to Tanner stages (I to V) by a certified nurse practitioner. BMI was calculated by weight (kg) divided by height (m) squared. The present study examined the following body composition variables: FM, FFM, visceral fat and skeletal muscle. Changes in these body composition variables are defined as the difference between baseline and post-intervention measurements.

Statistical Analysis

Participant baseline age, sex, body weight, ethnicity, Tanner stage, BMI, RMR and body composition variables were stratified by exercise modality and presented as means with standard deviations for continuous variables or frequency and percentages for categorical variables. Oneway ANOVA with Tukey post hoc test was used to determine baseline differences in RMR and body composition variables between exercise groups in comparison to the control group.

Linear regression models were used to analyze the differences between exercise modality on the changes in RMR, FM, visceral fat, FFM and skeletal muscle. Models were adjusted for age, sex, ethnicity, Tanner stages and respective baseline value of RMR, FM, visceral fat, FFM and skeletal muscle. Differences in RMR and body composition changes by exercise modality were presented as least squared mean. Linear regression models were also used to examine the individual relationship between changes over the intervention in RMR with changes in FM, visceral fat, FFM and skeletal muscle, with individuals in the control group excluded from the analyses. All models were adjusted for age, sex, ethnicity, Tanner stages, exercise modality and baseline RMR. Individuals with a Tanner stage of 4.5 were categorized as a Tanner stage 5. P values of <0.05 were considered statistical significant. All analyses were performed using the statistical program SAS 9.4 (Cary, N.C., USA).

3.4 Results

Participant baseline characteristics stratified by exercise modality are presented in **Table 1.** No significant differences in baseline FM, FFM, visceral fat or skeletal muscle mass were observed among the exercise groups compared to control ($p>0.05$). In contrast, those in the combined group had a lower RMR as compared to the control group at baseline ($p<0.05$). At baseline, RMR was significantly correlated with FM ($r= 0.41$, $p<0.0001$), FFM ($r= 0.69$, $p<0.0001$), visceral fat ($r= 0.43$, $p<0.0001$) and skeletal muscle mass ($r= 0.66$, $p<0.0001$).

Mean changes in RMR and body composition variables adjusted for its respective baseline measurements, age, sex, ethnicity and Tanner stage are shown in **Figure 1.** Changes in RMR (**Fig. 1A**) were not significantly different between exercise modalities (ΔRMR_{AT}= 41 kcal/day; ΔRMR_{RT}= 9 kcal/day; $\Delta RMR_{Combined}$= 12 kcal/day) and control (ΔRMR= -19 kcal/day). Only the aerobic group (-1.2 ± 0.5 kg) had significant decreases in body weight (**Fig. 1B**) compared to control (1.7 ± 0.9 kg), whereas significant reductions in fat mass (**Fig. 1C**) were observed in aerobic (-1.9 ± 0.4 kg) and resistance groups (-1.0 ± 0.4 kg) versus control (0.6 ± 0.7 kg). All exercise groups also had a reduction in visceral fat (**Fig. 1D**) (-0.2 ± 0.02 kg) relative to control (0.06 ± 0.04 kg). Significant increases in fat free mass (**Fig. 1E**) was seen only in the combined group (2.3 kg ± 0.4 kg) versus control (0.9 ± 0.4 kg) whereas increases in skeletal muscle (**Fig. 1F**) were seen in both the resistance (1.2 ± 0.2 kg) and combined (1.5 ± 0.3 kg) groups when compared to control (0.4 ± 0.3 kg).

The relationship between changes in body composition on RMR changes are presented in **Table 2** adjusted for age, sex, ethnicity, Tanner stages, exercise modality and baseline RMR with the control group excluded from these analyses. Partial R^2 for each body composition variable and its covariates are presented in **Appendix B.** The type of exercise modality did not have a significant effect on the associations between body composition variables and RMR change (ie. exercise modality x body composition variable interaction, $p>0.05$). Only changes in fat free mass appeared to be associated with RMR change ($p=0.04$).

Table 1 – Baseline subject characteristics (n=140)

	Control	**Aerobic exercise**	**Resistance exercise**	**Combined exercise**
n	18	51	50	21
Male/female (n)	11/7	20/31	21/29	7/14
Tanner stages (Stage V)	13 (72%)	39 (76%)	33 (66%)	16 (76%)
White ethnicity	8 (44%)	22 (43%)	20 (40%)	8 (38%)
Age (years)	14.6±1.7	14.8±1.7	14.5±1.6	14.6±1.7
Weight (kg)	99.0±16.4	95.2±17.9	92.8±12.9	90.2±14.8
BMI (kg/m^2)	35.4±5.5	33.9±4.5	34.1±3.4	31.7±3.4†
BMI (percentile)	98.7±1.3	98.2±1.7	98.6±1.0	97.5±1.8
RMR (kcals/day)	2034±293	1867±336	1841±329	1723±296†
DXA:				
Fat mass (kg)	43.0±11.2	39.3±9.7	39.8±8.2	36.4±9.0
Fat free mass (kg)	55.4±8.8	55.4±10.2	52.3±7.3	53.5±8.8
MRI:				
Visceral fat (kg)	1.2±0.5	1.3±0.6	1.3±0.5	1.3±0.6
Skeletal muscle (kg)	25.5±5.0	26.0±6.0	24.3±4.2	25.0±4.7

Data are means ± SD or frequency (percent %). BMI, body mass index; RMR, resting metabolic rate; DXA, dual-energy X-ray absorptiometry; MRI, magnetic resonance imaging
†p<0.05 compared to control group

Table 2 – The relationship between the changes in body composition and RMR (n=122)

	Model R^2	**Partial R^2**	***β* (SE) for ΔRMR**	***p***
Changes in body composition:				
Fat mass (kg)	0.18	0.001	7.4 (6.0)	0.22
Visceral fat (kg)	0.17	0.005	63.4 (85.6)	0.46
Fat free mass (kg)	0.20	0.046	20.5 (10.0)	**0.04**
Skeletal muscle (kg)	0.17	0.001	5.3 (11.6)	0.64

All models adjusted for age, sex, ethnicity, Tanner stages, exercise modality and baseline RMR
β values for the change in RMR per kg change in body composition
Control group excluded from analyses

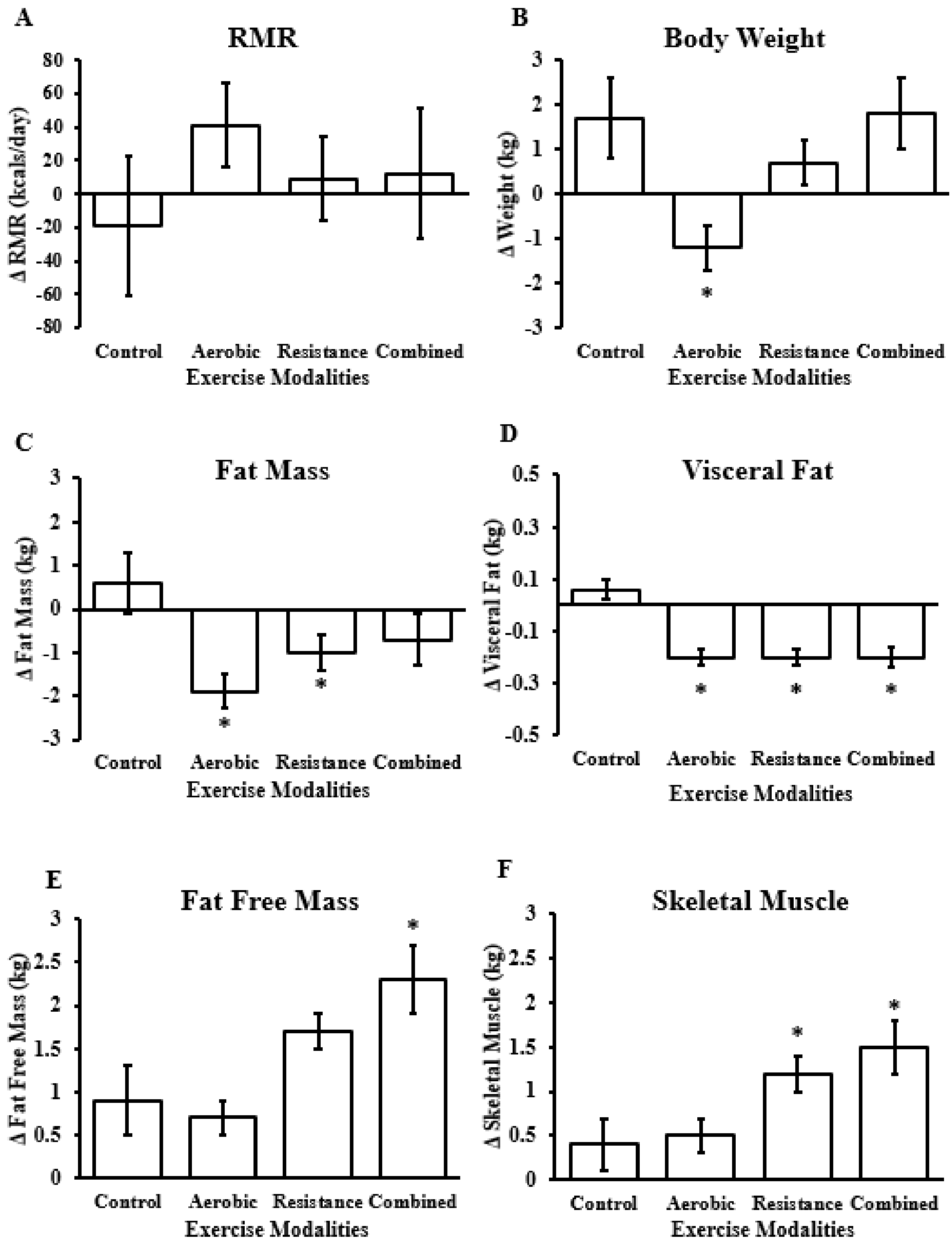


Figure 1 (A-F): Mean changes ± SE in RMR, body weight, FM, visceral fat, FFM and skeletal muscle in control, aerobic, resistance and combined exercise groups. All analyses adjusted for age, sex, ethnicity, Tanner stages and respective baseline measurements

*p<0.05 as compared to control group

3.5 Discussion

The present study examined the effects of different exercise modalities on RMR change and the relationship between changes in body composition and RMR in youth with overweight or obesity. Findings showed that exercise, regardless of modality, was not associated with significant changes in RMR and that changes in FFM but not FM, visceral fat or skeletal muscle was a significant predictor of RMR change.

Exercise has been recommended as an important component of weight management therapies [57,61]. However, it is unclear whether exercise training will improve RMR in youth with overweight or obesity. Few studies have examined the effects of exercise modalities on RMR in youth. To our knowledge, only one randomized control trial, the HEARTY trial [51], compared the effects of aerobic, resistance and combined exercise training on RMR change in post-pubertal youth with overweight or obesity. The researchers showed that with modest dietary restrictions (-250 kcal/day), exercise training, regardless of modality, was not associated with changes in RMR. However, it is important to note that participants of the study had low adherence to their respective exercise programs. The present study examined the independent effects of exercise modalities on RMR changes without dietary restrictions. All exercise groups were also prescribed similar exercise durations (180 mins/ week). Our results further support those of the HEARTY trial and demonstrated that without dietary restriction and a higher exercise intervention adherence (≥90% vs. ~60%), aerobic and/or resistance exercise training was not associated with changes in RMR despite inducing improvements in FFM and reductions in obesity.

Given the strong association between FFM and RMR [7,53], it has been proposed that resistance exercise should improve RMR by increasing muscle mass. In Treuth et al [50], although the researchers reported an increase in RMR (380 kcal/day) and FFM (2.1 kg) after resistance training in youth with obesity, the control group also experienced similar increases in both RMR (410 kcal/day) and FFM (1.9 kg), which may reflect differences with normal growth as opposed to exercise training. In contrast, several studies examining the effects of resistance exercise on RMR in weight-stable adults with [9] or without obesity [62] reported an increase in absolute RMR after exercise training. This may have been attributed to the increase in FFM observed with resistance exercise. Skeletal muscle is also the only modifiable component of FFM in adults whereas youth are undergoing growth such that both skeletal muscle and other FFM depots such as metabolically active organs are growing in size. In youth, organs also contribute a greater proportion to FFM [63] such that they have a lower skeletal muscle to lean mass ratio than adults. This may explain why resistance exercise in the present study was associated with significant improvements in skeletal muscle, but not FFM when compared to the control group.

We and others [13,51,62] show that aerobic exercise was not associated with changes in RMR. This is not surprising given that aerobic exercise generally is not associated with changes in muscle mass [52]. Although aerobic exercise was the only exercise training group associated with both weight and fat loss, RMR was not significantly reduced. It may be attributed to the low metabolic activity in fat mass [64,65] and that aerobic exercise was not associated with reductions in FFM in the present study. This suggests that exercise weight loss may not be associated with reductions in RMR that are often reported with dietary weight loss in adults and children [54–56].

It is well supported in the literature that FFM is a primary determinant of RMR [5,7,53]. Similarly, we have demonstrated that changes in FFM is associated with RMR change in youth with overweight or obesity. In fact, changes in FFM was the only body composition variable examined that had a significant, though modest, association with RMR change such that an increase in 1 kg of fat free mass is associated with a 21 kcal/day RMR change. Previous studies that report increases in absolute RMR generally also report an increase in FFM [9,47,50]. However, despite the relationship between FFM change and RMR change being statistically significant, the small change in RMR observed is likely not clinically meaningful as it would require large increases in FFM to see improvements in RMR. We demonstrated that with 3 to 6 months of exercise training, only a mean of 0.7 to 2.3 kg FFM increase from baseline was observed in youth with overweight or obesity which translates to an increase in absolute RMR of approximately 9 to 41 kcal/day (0.5% to 2.2 % of baseline RMR).

There are strengths and limitations in the study that merit discussion. Findings from the study contribute to the limited literature on the effects of exercise on RMR change in youth with overweight or obesity. This study includes participants with high adherence (≥90%) to their respective training programs. RMR measurements were also taken 72 hours after the last bout of exercise to allow acute effects of exercise (ie. EPOC) to dissipate. Therefore, changes in RMR observed would unlikely be due to acute effects of exercise. A limitation of the study includes the utilization of indirect calorimetry with a ventilated hood instead of whole room indirect calorimeter [66]. Fidgeting during testing and discomfort in using the ventilated hood may contribute to higher variances and overestimation of RMR. Small sample sizes and examination of only black and white youth also limits our ability to examine sex and racial effects on the relationship between exercise modalities and RMR changes.

In conclusion, findings from the present study show that different exercise modalities, whether it is aerobic, resistance, or a combination of the two exercises, are not associated with significant changes in RMR in youth with overweight or obesity. Regardless of the type of exercise performed, changes in FFM is a modest predictor of RMR change. Therefore, we propose that moderate exercise training in youth with overweight or obesity is not associated with changes in RMR.

4.0 General Conclusion

Childhood obesity is an international health issue of today's society. Obesity is a complex disease arising from multiple factors that include, but are not limited to, genetics, physiological and sociocultural factors and the environment [25]. What is concerning is that children with obesity are more likely to develop cardiovascular disorders as adults [17,18] and have a greater risk of early mortality [67]. According to the World Obesity Federation, more than 250 million children and adolescents are estimated to have obesity by 2030 [68], thus, emphasizing the importance of prevention and treatment.

Current recommendations in addressing childhood obesity is the incorporation of physical activity into weight management programs [61]. Although the health benefits of physical activity are well documented in the literature, it may be difficult to lose and maintain significant amounts of weight loss with exercise alone. Possible mechanisms that contribute to the less than expected weight loss may include physiological [69], behavioural and metabolic compensations [27] to weight changes. Specifically, RMR reductions with weight loss has been proposed to be a contributor of weight regain. Interestingly, previous studies have found that resistance exercise training in adults was able to conserve RMR with weight loss through the preservation of FFM [49]. Findings from the present study further contributed to the limited literature on this relationship in youth with overweight or obesity.

In conclusion, we have demonstrated that moderate exercise training, regardless of modality, was not associated with changes in RMR and that FFM change was a modest predictor of RMR change in youth with overweight or obesity.

References

1. Di Angelantonio E, Bhupathiraju SN, Wormser D, Gao P, Kaptoge S, de Gonzalez AB, et al. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. Lancet. 2016;388: 776–786. doi:10.1016/S0140-6736(16)30175-1

2. Bhaskaran K, Douglas I, Forbes H, Dos-Santos-Silva I, Leon DA, Smeeth L. Body-mass index and risk of 22 specific cancers: A population-based cohort study of 5·24 million UK adults. Lancet. Bhaskaran et al. Open Access article distributed under the terms of CC BY; 2014;384: 755–765. doi:10.1016/S0140-6736(14)60892-8

3. Kinlen D, Cody D, O'Shea D. Complications of Obesity [Internet]. QJM. 2018. pp. 437–443. doi:10.1093/qjmed/hcx152

4. Poehlman ET. A review: exercise and its influence on resting energy metabolism in man. Medicine and Science in Sports and Exercise 1989 pp. 515–525. doi:10.1249/00005768-198910000-00005

5. Molnár D, Schutz Y. The effect of obesity, age, puberty and gender on resting metabolic rate in children and adolescents. Eur J Pediatr. 1997;156: 376–381. doi:10.1007/s004310050618

6. Bitar A, Fellmann N, Vernet J, Coudert J, Vermorel M. Variations and determinants of energy expenditure as measured by whole- body indirect calorimetry during puberty and adolescence. Am J Clin Nutr. 1999;69: 1209–1216. doi:10.1093/ajcn/69.6.1209

7. Johnstone AM, Murison SD, Duncan JS, Rance KA, Speakman JR. Factors influencing variation in basal metabolic rate include fat-free mass, fat mass, age, and circulating thyroxine but not sex, circulating leptin, or triiodothyronine. Am J Clin Nutr. Narnia; 2005;82: 941–948. doi:10.1093/ajcn/82.5.941

8. Schwartz A, Kuk JL, Lamothe G, Doucet É. Greater than predicted decrease in resting energy expenditure and weight loss: Results from a systematic review. Obesity. 2012;20: 2307–2310. doi:10.1038/oby.2012.34

9. Byrne HK, Wilmore JH. The effects of a 20-week exercise training program on resting metabolic rate in previously sedentary, moderately obese women. Int J Sport Nutr. 2001;11: 15–31. doi:10.1123/ijsnem.11.1.15

10. Lee M-G, Sedlock DA, Flynn MG, Kamimori GH. Resting Metabolic Rate after Endurance Exercise Training. Med Sci Sport Exerc. 2009;41: 1444–1451. doi:10.1249/MSS.0b013e31819bd617

11. Potteiger JA, Kirk EP, Jacobsen DJ, Donnelly JE. Changes in resting metabolic rate and substrate oxidation after 16 months of exercise training in overweight adults. Int J Sport Nutr Exerc Metab. 2008;18: 79–95. doi:10.1123/ijsnem.18.1.79

12. Hunter GR, Byrne NM, Sirikul B, Fernández JR, Zuckerman PA, Darnell BE, et al. Resistance training conserves fat-free mass and resting energy expenditure following

weight loss. Obesity. 2008;16: 1045–1051. doi:10.1038/oby.2008.38

13. Santa-Clara H, Szymanski L, Ordille T, Fernhall B. Effects of exercise training on resting metabolic rate in postmenopausal African American and Caucasian women. Metabolism. 2006;55: 1358–1364. doi:10.1016/j.metabol.2006.06.006

14. Obesity and Overweight. World Heal Fact Sheet. 1980; Available: https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight

15. Hales CM, Carroll MD, Fryar CD, Ogden CL. Prevalence of Obesity Among Adults and Youth: United States, 2015-2016 Key findings Data from the National Health and Nutrition Examination Survey [Internet]. 2015. Available: https://www.cdc.gov/nchs/data/databriefs/db288_table.pdf#1.

16. NCD Risk Factor Collaboration (NCD-RisC) L, Abdeen ZA, Hamid ZA, Abu-Rmeileh NM, Acosta-Cazares B, Acuin C, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet (London, England). Elsevier; 2017;390: 2627–2642. doi:10.1016/S0140-6736(17)32129-3

17. Gepstein V, Weiss R. Obesity as the Main Risk Factor for Metabolic Syndrome in Children. Front Endocrinol (Lausanne). Frontiers Media SA; 2019;10. doi:10.3389/fendo.2019.00568

18. Goodman E, Dolan LM, Morrison JA, Daniels SR. Factor analysis of clustered cardiovascular risks in adolescence: Obesity is the predominant correlate of risk among youth. Circulation. 2005;111: 1970–1977. doi:10.1161/01.CIR.0000161957.34198.2B

19. Murphy SL, Xu J, Kochanek KD, Curtin SC, Arias E. National Vital Statistics Reports Volume 66, Number 6, November 27, 2017 [Internet]. National Vital Statistics Reports. 2015. Available: https://www.cdc.gov/

20. Cohen JB. Hypertension in Obesity and the Impact of Weight Loss. Curr Cardiol Rep. 2017;19. doi:10.1007/s11886-017-0912-4

21. Grams J, Garvey WT. Weight Loss and the Prevention and Treatment of Type 2 Diabetes Using Lifestyle Therapy, Pharmacotherapy, and Bariatric Surgery: Mechanisms of Action. Curr Obes Rep. 2015;4: 287–302. doi:10.1007/s13679-015-0155-x

22. Feingold KR GC. Obesity and Dyslipidemia - Endotext - NCBI Bookshelf. 2018. Available: https://www.ncbi.nlm.nih.gov/books/NBK305895/

23. Wolfe BM, Kvach E, Eckel RH. Treatment of obesity. Circulation Research. Lippincott Williams and Wilkins; 2016. pp. 1844–1855. doi:10.1161/CIRCRESAHA.116.307591

24. Pearl RL, Wadden TA, Tronieri JS, Berkowitz RI, Chao AM, Alamuddin N, et al. Short- and Long-Term Changes in Health-Related Quality of Life with Weight Loss: Results from a Randomized Controlled Trial. Obesity. 2018;26: 985–991. doi:10.1002/oby.22187

25. Bray GA, Frühbeck G, Ryan DH, Wilding JPH. Management of obesity. www.thelancet.com. 2016;387. doi:10.1016/S0140-6736(16)00271-3

26. Wadden TA. Treatment of Obesity by Moderate and Severe Caloric Restriction Results of Clinical Research Trials [Internet]. 1993. Available: http://annals.org/

27. King NA, Caudwell P, Hopkins M, Byrne NM, Colley R, Hills AP, et al. Metabolic and behavioral compensatory responses to exercise interventions: Barriers to weight loss. Obesity. 2007;15: 1373–1383. doi:10.1038/oby.2007.164

28. Sharma AM, Padwal R. Obesity is a sign - over-eating is a symptom: an aetiological framework for the assessment and management of obesity. Obes Rev. 2010;11: 362–370. doi:10.1111/j.1467-789X.2009.00689.x

29. Lam YY, Ravussin E. Indirect calorimetry: an indispensable tool to understand and predict obesity. Nat Publ Gr. 2017;71: 318–322. doi:10.1038/ejcn.2016.220

30. Adriaens MPE, Schoffelen PFM, Westerterp KR. Intra-individual variation of basal metabolic rate and the influence of daily habitual physical activity before testing. Br J Nutr. 2003;90: 419–423. doi:10.1079/bjn2003895

31. Ventham JC, Reilly JJ. Reproducibility of resting metabolic rate measurement in children. Br J Nutr. 1999;81: 435–437. doi:10.1017/S0007114599000781

32. Haugen HA, Melanson EL, Tran ZV, Kearney JT, Hill JO. Variability of measured resting metabolic rate. Am J Clin Nutr. 2003;78: 1141–1144. doi:10.1093/ajcn/78.6.1141

33. Jackson DM, Pace L, Speakman JR. The measurement of resting metabolic rate in preschool children. Obesity. John Wiley & Sons, Ltd; 2007;15: 1930–1932. doi:10.1038/oby.2007.230

34. Figueroa-Colon R, Franklin FA, Goran MI, Lee JY, Weinsier RL. Reproducibility of measurement of resting energy expenditure in prepubertal girls. Am J Clin Nutr. 1996;64: 533–536. doi:10.1093/ajcn/64.4.533

35. Cheng HL, Amatoury M, Steinbeck K. Energy expenditure and intake during puberty in healthy nonobese adolescents: a systematic review. Am J Clin Nutr. Narnia; 2016;104: 1061–1074. doi:10.3945/ajcn.115.129205

36. Sun M, Gower BA, Bartolucci AA, Hunter GR, Figueroa-Colon R, Goran MI. A longitudinal study of resting energy expenditure relative to body composition during puberty in African American and white children. Am J Clin Nutr. 2001;73: 308–315. doi:10.1093/ajcn/73.2.308

37. Speakman JR, Selman C. Physical activity and resting metabolic rate. Proc Nutr Soc. Nutrition Society; 2003;62: 621–634. doi:10.1079/pns2003282

38. Børsheim E, Bahr R. Effect of Exercise Intensity, Duration and Mode on Post-Exercise Oxygen Consumption. Sports Med. 2003.

39. Gaesser GA, Brooks GA. Metabolic bases of excess post-exercise oxygen consumption: a review. Med Sci Sport Exerc. 1984;16: 29–43.

40. Burleson MA, O'Bryant HS, Stone MH, Collins MA, Triplett-McBride T. Effect of weight training exercise and treadmill exercise on post-exercise oxygen consumption.

Med Sci Sports Exerc. Med Sci Sports Exerc; 1998;30: 518–522. doi:10.1097/00005768-199804000-00008

41. Laforgia J, Withers RT, Gore CJ. Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. J Sports Sci. 2006;24: 1247–1264. doi:10.1080/02640410600552064

42. Hackney KJ, Engels HJ, Gretebeck RJ. Resting energy expenditure and delayed-onset muscle soreness after full-body resistance training with an eccentric concentration. J Strength Cond Res. 2008;22: 1602–1609. doi:10.1519/JSC.0b013e31818222c5

43. Lee S, Bacha F, Hannon T, Kuk JL, Boesch C, Arslanian S. Effects of aerobic versus resistance exercise without caloric restriction on abdominal fat, intrahepatic lipid, and insulin sensitivity in obese adolescent boys: a randomized, controlled trial. Diabetes. American Diabetes Association; 2012;61: 2787–95. doi:10.2337/db12-0214

44. Oh M, Kim Y, Suh S-H, Jeon JY. Effects of Resistance Exercise Training on Childhood Obesity. Korean J Obes. 2014;23: 141. doi:10.7570/kjo.2014.23.3.141

45. Müller MJ, Bosy-Westphal A, Kutzner D, Heller M. Metabolically active components of fat-free mass and resting energy expenditure in humans: Recent lessons from imaging technologies. Obesity Reviews. 2002. pp. 113–122. doi:10.1046/j.1467-789X.2002.00057.x

46. Nelson KM, Weinsier RL, Long CL, Schutz Y. Prediction of resting energy expenditure from fat-free mass and fat mass. Am J Clin Nutr. 1992;56: 848–856. doi:10.1093/ajcn/56.5.848

47. Aristizabal JC, Freidenreich DJ, Volk BM, Kupchak BR, Saenz C, Maresh CM, et al. Effect of resistance training on resting metabolic rate and its estimation by a dual-energy X-ray absorptiometry metabolic map. Eur J Clin Nutr. Nature Publishing Group; 2015;69: 831–836. doi:10.1038/ejcn.2014.216

48. Stavres JR, Zeigler MP, Bayles MP. Six Weeks of Moderate Functional Resistance Training Increases Basal Metabolic Rate in Sedentary Adult Women [Internet]. International Journal of Exercise Science. 2018. Available: http://www.intjexersci.com

49. Miller T, Mull S, Aragon AA, Krieger J, Schoenfeld BJ. Resistance training combined with diet decreases body fat while preserving lean mass independent of resting metabolic rate: A randomized trial. Int J Sport Nutr Exerc Metab. 2018;28: 46–54. doi:10.1123/ijsnem.2017-0221

50. Treuth MS, Hunter GR, Pichon C, Figueroa-Colon R, Goran MI. Fitness and energy expenditure after strength training in obese prepubertal girls. Med Sci Sports Exerc. 1998;30: 1130–1136. doi:10.1097/00005768-199807000-00017

51. Alberga AS, Prud'Homme D, Sigal RJ, Goldfield GS, Hadjiyannakis S, Gougeon R, et al. Does exercise training affect resting metabolic rate in adolescents with obesity? Appl Physiol Nutr Metab. 2016;42: 15–22. doi:10.1139/apnm-2016-0244

52. Pollock ML, Franklin BA, Balady GJ, Chaitman BL, Fleg JL, Fletcher B, et al. Resistance exercise in individuals with and without cardiovascular disease: Benefits, rationale, safety,

and prescription: An advisory from the Committee on Exercise, Rehabilitation, and Prevention, Council on Clinical Cardiology, American Heart Association. Circulation. Lippincott Williams and Wilkins; 2000;101: 828–833. doi:10.1161/01.CIR.101.7.828

53. Müller MJ, Bosy-Westphal A, Later W, Haas V, Heller M. Functional body composition: insights into the regulation of energy metabolism and some clinical applications. Eur J Clin Nutr. 2009;63: 1045–1056. doi:10.1038/ejcn.2009.55

54. Kiortsis DN, Durack I, Turpin G. Effects of a low-calorie diet on resting metabolic rate and serum tri- iodothyronine levels in obese children. Eur J Pediatr. 1999;158: 446–450. doi:10.1007/s004310051117

55. Leibel RL, Rosenbaum M, Hirsch J. Changes in energy expenditure resulting from altered body weight. N Engl J Med. 1995;332: 621–628. doi:10.1056/NEJM199503093321001

56. Menozzi R, Bondi M, Baldini A, Venneri MG, Velardo A, Del Rio G. Resting metabolic rate, fat-free mass and catecholamine excretion during weight loss in female obese patients. Br J Nutr. 2000;84: 515–520. doi:10.1017/s0007114500001823

57. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: A report of the American College of cardiology/American Heart Association task force on practice guidelines and the obesity society [Internet]. Circulation. Lippincott Williams and Wilkins; 2014. pp. S102–S138. doi:10.1161/01.cir.0000437739.71477.ee

58. Lee S, Bacha F, Hannon T, Kuk JL, Boesch C, Arslanian S. Effects of Aerobic Versus Resistance Exercise Without Caloric Restriction on Abdominal Fat, Intrahepatic Lipid, and Insulin Sensitivity in Obese Adolescent Boys: A Randomized, Controlled Trial. Diabetes. 2012;61: 2787–2795. doi:10.2337/db12-0214

59. Lee SJ, Deldin AR, White D, Kim YM, Libman I, Rivera-Vega M, et al. Aerobic exercise but not resistance exercise reduces intrahepatic lipid content and visceral fat and improves insulin sensitivity in obese adolescent girls: A randomized controlled trial. Am J Physiol - Endocrinol Metab. American Physiological Society; 2013;305. doi:10.1152/ajpendo.00285.2013

60. Lee SJ, Libman I, Hughan K, Kuk JL, Jeong JH, Zhang D, et al. Effects of Exercise Modality on Insulin Resistance and Ectopic Fat in Adolescents with Overweight and Obesity: A Randomized Clinical Trial. J Pediatr. Elsevier Inc.; 2019;206: 91-98.e1. doi:10.1016/j.jpeds.2018.10.059

61. Spear BA, Barlow SE, Ervin C, Ludwig DS, Saelens BE, Schetzina KE, et al. Recommendations for treatment of child and adolescent overweight and obesity. Pediatrics. 2007. doi:10.1542/peds.2007-2329F

62. Poehlman ET, Denino WF, Beckett T, Kinaman KA, Dionne IJ, Dvorak R, et al. Effects of Endurance and Resistance Training on Total Daily Energy Expenditure in Young Women: A Controlled Randomized Trial. J Clin Endocrinol Metab. Endocrine Society; 2002;87: 1004–1009. doi:10.1210/jcem.87.3.8282

63. Gallagher D, Elia M. Body Composition, Organ Mass and Resting Energy Expenditure.

In: Heymsfield SB, Lohman TG, Wang Z, Going SB, editors. Human Body Composition, Volumne 918. 2nd ed. Human Kinetics; 2005. pp. 219–239.

64. Wang ZM, Ying Z, Bosy-Westphal A, Zhang J, Schautz B, Later W, et al. Specific metabolic rates of major organs and tissues across adulthood: Evaluation by mechanistic model of resting energy expenditure. Am J Clin Nutr. American Society for Nutrition; 2010;92: 1369–1377. doi:10.3945/ajcn.2010.29885

65. Elia M. Organ and tissue contribution to metabolic rate. In: Kinney J, Tucker H, editors. Energy Metabolism: Tissue Determinants and Cellular Corollaries. New York: Raven Press; 1992. pp. 61–80.

66. Rising R, Whyte K, Albu J, Pi-Sunyer X. Evaluation of a new whole room indirect calorimeter specific for measurement of resting metabolic rate. Nutr Metab. BioMed Central Ltd.; 2015;12. doi:10.1186/s12986-015-0043-0

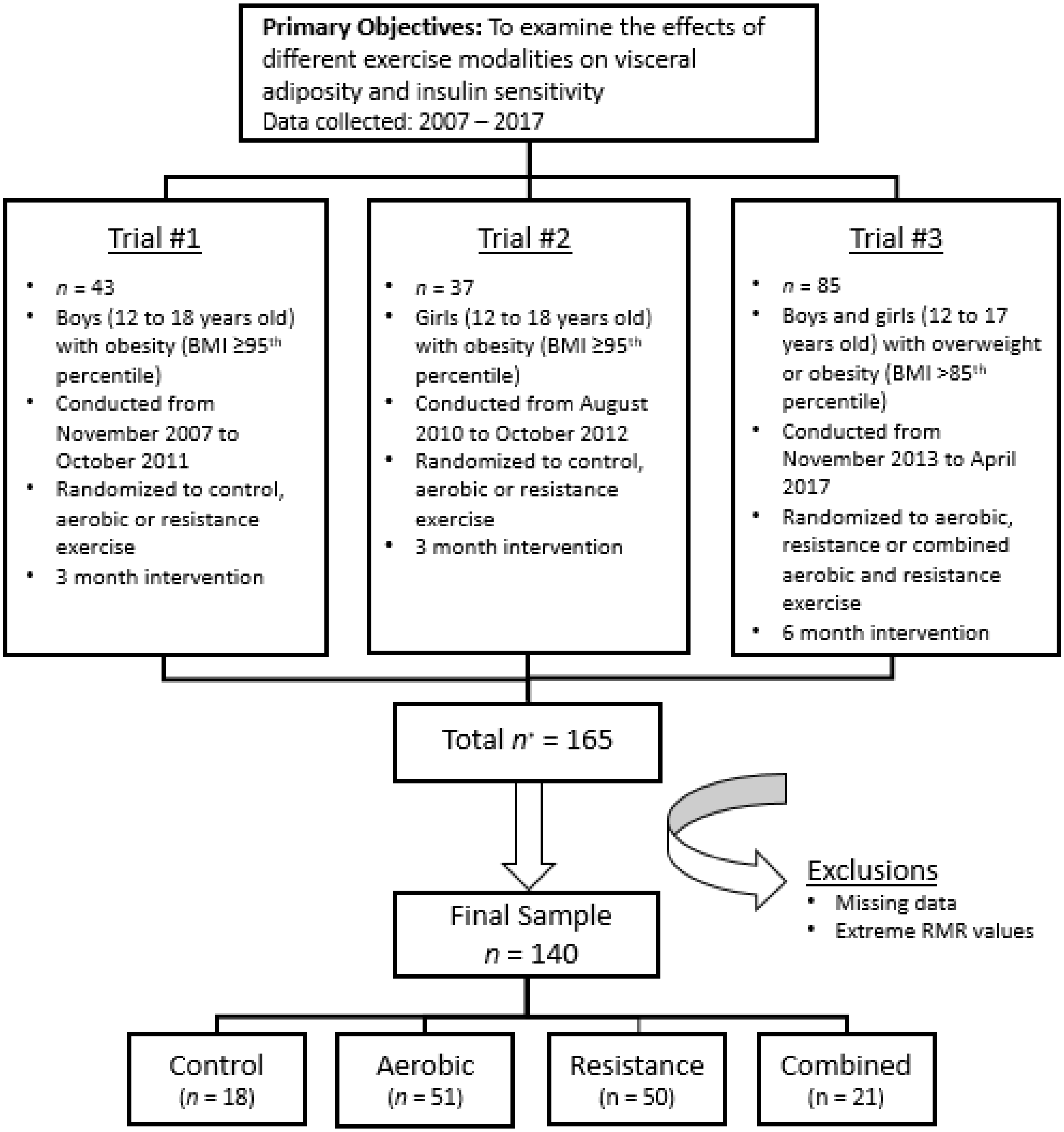
67. Lindberg L, Danielsson P, Persson M, Marcus C, Hagman E. Association of childhood obesity with risk of early all-cause and cause-specific mortality: A Swedish prospective cohort study. Persson LÅ, editor. PLOS Med. NLM (Medline); 2020;17: e1003078. doi:10.1371/journal.pmed.1003078

68. Lobstein T, Brinsden H. Atlas of Childhood Obesity [Internet]. World Obesity Federation. 2019. Available: www.worldobesity.org

69. Greenway FL. Physiological adaptations to weight loss and factors favouring weight regain. International Journal of Obesity. Nature Publishing Group; 2015. pp. 1188–1196. doi:10.1038/ijo.2015.59

Appendices

Appendix A: Primary Data – Participant Flow Diagram



Participant flow diagram of the three primary exercise intervention studies included in the secondary analysis. All exercise intervention trials and primary data collection was completed at the University of Pittsburgh Medical Center

*n= only participants who completed their respective intervention were included

Appendix B: Partial R^2 of Covariates

Partial R^2 of covariates within regression models the relationship between body composition change and RMR change

	Fat Mass	***p* value**	**Visceral Fat**	***p* value**	**Fat Free Mass**	***p* value**	**Skeletal Muscle**	***p* value**
	0.001	0.2	0.005	0.5	0.046	**0.04**	0.001	0.6
Covariates:								
Age (years)	0.0001	0.7	0.00003	0.5	0.011	0.9	0.0003	0.6
Sex	0.110	**0.0002**	0.101	**0.0003**	0.055	**0.0049**	0.096	**0.0004**
Ethnicity	0.006	0.4	0.005	0.4	0.008	0.3	0.005	0.4
Tanner stages	0.005	0.4	0.006	0.4	0.006	0.4	0.006	0.4
Exercise modality: Aerobic	0.002	0.3	0.001	0.4	0.013	0.2	0.002	0.4
Exercise modality: Combined	0.002	1.0	0.003	0.9	0.001	0.9	0.002	1.0
Baseline RMR (kcal/day)	0.055	**<.0001**	0.053	**<.0001**	0.061	**<.0001**	0.058	**<.0001**

Regression models adjusted for age, sex, ethnicity, Tanner stages, exercise modality and baseline RMR. Resistance exercise (reference), control group excluded from analyses.