The effects of aerobic and resistance exercise training on the cardiometabolic health of adolescents with obesity

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ABSTRACT

Physical inactivity and obesity in adolescence are associated with an increased risk of cardiovascular disease (CVD). Although exercise is recommended for the management of obesity, we know little about which types of exercise training are the most effective in reducing excess body fat and improving CVD risk in obese adolescents. This dissertation examined the effects of aerobic training, resistance training and their combination on the cardiometabolic health (body composition, CVD risk markers, resting metabolic rate (RMR), and fitness) of obese adolescents who participated in the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) trial. After a 4-week supervised moderate-intensity exercise run-in period, 304 overweight and obese adolescents were randomized to 4 groups for 22 weeks: Aerobic training, Resistance training, Combined aerobic and resistance exercise training, or a non-exercising Control. All four groups received dietary counseling designed to promote healthy eating with a maximum daily energy deficit of 250 kcal. Participants were assessed at baseline and after 3 and 6 months. Body composition was assessed using magnetic resonance imaging. Blood tests for traditional and non-traditional CVD risk markers were measured after a 12-hour fast. RMR and cardiorespiratory fitness were assessed using indirect calorimetry at rest and during a maximal treadmill test respectively. Musculoskeletal fitness (muscular strength, endurance, flexibility) was assessed using eight repetition maximum tests (8-RM) on the leg press, chest press and upright row machines and using the Canadian Society for Exercise Physiology- Canadian Physical Activity Fitness and Lifestyle Appraisal (CSEP-CPAFLA) tests for grip strength, push-ups, sit-ups, sit and reach and vertical jump. Decreases in percent body fat and abdominal fat were greatest in the combined training group. Although body weight, RMR and traditional CVD risk markers did not improve following the exercise intervention, the combined training group showed improvements in cardiorespiratory and musculoskeletal fitness and some non-traditional CVD risk markers. Cumulatively, combined aerobic and resistance exercise training showed the greatest improvements in cardiometabolic health in overweight and obese adolescents. This thesis concludes with a knowledge translation article detailing the practical lessons learned from exercise interventions with obese youth with hopes of increasing adherence to future exercise programs and improving the overall health of children and adolescents with obesity.

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LIST OF ABBREVIATIONS

Aerobic	Aerobic exercise training group
ApoA-1	Apolipoprotein A-1
ApoB	Apolipoprotein B
BMI	Body mass index
Combined	Combined aerobic and resistance exercise training group
CPAFLA	Canadian Physical Activity Fitness and Lifestyle Appraisal
CRF	Cardiorespiratory fitness
CSEP	Canadian Society for Exercise Physiology
CVD	Cardiovascular disease
deepSAT	Deep layer of abdominal subcutaneous adipose tissue
HbA1c	Hemoglobin A1c
HDL	High-density lipoprotein cholesterol
HEARTY	Healthy Eating Aerobic and Resistance Training in Youth
HSCRP	High-sensitivity C-reactive protein
kcal	kilocalories
LDL	Low-density lipoprotein cholesterol
ITT	Intention-to-treat analysis (includes entire sample, even dropouts)
MRI	Magnetic resonance imaging
PA	Physical activity
PP	Per-protocol analysis (includes only participants with ≥70% adherence)
Resistance	Resistance exercise training group
RMR	Resting metabolic rate
RM	Repetition maximum

SAT	Subcutaneous adipose tissue or subcutaneous fat
Superficial SAT	Superficial layer of abdominal subcutaneous adipose tissue
VAT	Visceral adipose tissue or visceral fat
VO_{2peak}	Peak oxygen consumption
%BF	Percent body fat

CHAPTER I: INTRODUCTION

General introduction

Physical inactivity (1) and childhood obesity (2-3) are great public health concerns. Adolescence has been described as a critical period for the onset, development and continuation of obesity throughout the lifespan (4-5). The prevalence of overweight and obesity among children and adolescents in Canada has doubled in the last thirty years from 15% in 1978–1979 (6) to 31.5% in 2009–2011 (7) while sport participation (8) and fitness levels (9-11) of Canadian youth have declined substantially in the same time period. Adolescents with obesity are less fit compared to their non-obese peers (12), have an increased risk of abdominal obesity (13), and are more likely to become obese adults (14-16). Furthermore, their increased cardiometabolic risk (17-18), is associated with developing the metabolic syndrome (19-21), type 2 diabetes mellitus (22) and cardiovascular disease (CVD) (23-24). Obese adolescents may particularly benefit from structured exercise training programs to improve their overall health and prevent the onset of chronic diseases and premature mortality.

Traditionally, regular aerobic exercise training (e.g. jogging, running, skipping, swimming etc.) performed 3-5 times weekly at moderate to vigorous intensity (50-75% VO_{2peak}) has been the most readily prescribed exercise modality for youth with obesity and is associated with improvements in cardiorespiratory fitness (25) and the prevention of CVD and premature mortality in adults (26). Although previous smaller studies showed that aerobic training increased cardiorespiratory fitness and decreased percent body fat, abdominal fat, and blood pressure, the effects of aerobic training on traditional and non-traditional CVD risk markers (i.e. plasma lipid levels, insulin resistance markers, high-sensitivity C-reactive protein and apolipoproteins) in overweight and obese adolescents are poorly understood (27).

Resistance exercise training, also known as strength training or weight training, (e.g. using free weights, weight machines or your own body weight as resistance etc.) has garnered more attention in recent years. This exercise modality may be more appealing than aerobic exercise to obese youth who show altered motor coordination, lower mechanical efficiency (28-29) and lower exercise tolerance (28, 30) that may be exacerbated by the weight-bearing nature of aerobic exercise. The few smaller studies showed conflicting results on percent body fat, lean tissue and muscular strength following resistance training (31). Further investigation is needed to determine the effects of this type of training on body composition, traditional and non-traditional CVD risk markers, resting metabolic rate (RMR) and fitness in overweight and obese adolescents.

Considering that obesity is the result of an imbalance between energy intake and energy expenditure, and that RMR accounts for the greatest percentage of total energy expenditure per day (32), determining whether or not exercise training can increase RMR or counteract the decrease that often occurs with weight loss, has important implications for energy balance and body weight management. In this regard, the literature in obese adults is inconsistent and the effects of different exercise modalities on RMR in obese adolescents are unknown and warrant further investigation.

Overall, very few studies have thoroughly examined the effects of aerobic training alone, resistance training alone and the combination of aerobic and resistance training on body composition, CVD risk markers, RMR, cardiorespiratory and musculoskeletal fitness of overweight and obese adolescents. The few studies that have been done were limited in their study designs (mixed prepubertal and postpubertal samples, small ethnic minorities, gender-specific samples, short study durations and lack of non-exercising control groups). These knowledge gaps limit the scope, generalizability and practical application of the effects of these exercise programs to improve the health of adolescents with obesity.

The Healthy Eating, Aerobic and Resistance Training in Youth (HEARTY) trial is the first randomized controlled trial designed to address these shortcomings. The primary objective of the HEARTY study was to evaluate the effects of resistance training, aerobic training, and combined training on percent body fat in obese post-pubertal overweight and obese adolescents aged 14 to 18 years.

Objectives

The objectives of this dissertation were to investigate the effects of different exercise training modalities (aerobic training, resistance training and both) from the HEARTY trial on:

1) Abdominal fat distribution and cardiovascular disease risk markers;
2) resting metabolic rate; and
3) cardiorespiratory and musculoskeletal fitness in obese adolescents.

Hypotheses

The hypotheses of this dissertation were that:

1) All three exercise training groups would demonstrate decreased abdominal fat and improvements in cardiovascular disease risk markers, with the largest effects in the combined group;
2) both the resistance training and combined training groups would show improvements in resting metabolic rate;
3) both the aerobic training and combined training groups would show increases in

cardiorespiratory fitness, with the largest effects in the combined training group; and both the resistance training and combined training groups would show improvements in musculoskeletal fitness, with the largest effects in the combined training group.

Structure of the thesis

In the course of achieving these objectives, the specific aims of this dissertation are to:

1. Evaluate and synthesize the literature on the multifactorial etiology of obesity and review the physiological and behavioral changes that typically occur during the critical period of adolescence (manuscript 1).
2. Identify the knowledge gaps and systematically review the existing literature regarding exercise training interventions on body composition, CVD risk markers and fitness in adolescents with obesity (manuscripts 2 and 3).
3. Describe the rationale, design and methodology of the HEARTY study highlighting the need to investigate the effects of aerobic training and resistance training on the health of obese adolescents (manuscript 4).
4. Determine the effects of aerobic training, resistance training and their combination on percent body fat, abdominal fat and CVD risk markers (manuscripts 5 and 6), RMR (manuscript 7) and cardiorespiratory and musculoskeletal fitness (manuscript 8) of obese adolescents who participated in the HEARTY trial.
5. Synthesize the practical lessons learned from the HEARTY trial, evaluate the existing literature on exercise interventions with obese youth and produce a knowledge translation paper to disseminate the practical application and novelty of this dissertation (manuscript 9).

CHAPTER II: LITERATURE REVIEW

MANUSCRIPT 1: Overweight and Obese Teenagers: Why is Adolescence a Critical Period?

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Permission was granted to include the published version of this article in this dissertation (Appendix).

Statement of contributions of collaborators:

A.S. Alberga conceived the topic and content of this review article, carried out the bibliographic search, article screening, evaluated the evidence and drafted and edited the manuscript. R.J. Sigal, G. Goldfield, D. Prud'homme and G.P. Kenny provided analytical input and helped draft and edit the manuscript.

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REVIEWARTICLE

Overweight and obese teenagers: why is adolescence a critical period?

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Summary

This paper discusses the critical period of adolescence and its potential role in the development and persistence of obesity. The adolescent years are characteristic of changes in body composition (location and quantity of body fat), physical fitness and decreased insulin sensitivity during puberty. This period of growth and maturation is also marked with behavioural changes in diet, physical activity, sedentary behaviour and psychological health. Physical activity and sport participation decline during adolescence especially in teenage girls, while sedentary behaviour, risk for depression and body esteem issues increase during the teenage years. These physiological and behavioural changes during adolescence warrant the attention of health practitioners to prevent the onset and continuation of obesity throughout the lifespan.

Keywords: Adolescence, obesity, maturation, physical activity.

Introduction

Considerable interest exists in the growth, development and maturation of youth and how these aspects of development relate to obesity in childhood and adulthood. Adolescence has been identified as one of the stages that may play a critical role in the development and persistence of obesity and related co-morbidities into adulthood (1).

This paper will discuss various physiological and behavioural changes that occur during adolescence that warrant attention for obesity prevention and management. Prevalence of adolescent obesity, changes in body composition, insulin sensitivity, puberty, maturation, fitness and important behavioural changes in diet, physical activity, sedentary behaviour and psychological health will be covered. For this paper, 'children' refers to those aged ≤ 12 years and 'adolescents' to those aged between 13 and 18 years.

Definition and prevalence of obesity in children and youth

In the past 20 years, childhood obesity has reached epidemic proportions worldwide (2–5). Body mass index [BMI; calculated by weight (kg)/height (m^2)] percentiles represented on age- and sex- matched growth curves are used to determine the degree of overweight/obesity in children and adolescents aged 2–20 years from the year 2000 (6). Children and adolescents between the 85th and 94th age- and sex-BMI percentile are considered 'overweight' while children and adolescents who are classified as 'obese' fall above the 95th BMI age- and sex-matched percentile.

The prevalence of obesity rates in Canadian children and adolescents aged 2–18 years increased by 11% from 1979 (15%) to 2004 (26%) (7). In the United States, approximately one-third of youth are considered overweight or obese (8). In 2004, the International Obesity Task Force stated that approximately 1 in 10 children and adolescents were considered overweight, amounting to 155 million worldwide (9). Of particular concern is the doubling prevalence of overweight or obese adolescents in industrialized nations like Canada from 14% in 1978–1979 to 29% in 2004 (7). Childhood BMI is related to adulthood adiposity and overweight and obese children have a greater risk of becoming obese adults than normal or underweight children (10,11). In fact, it has been shown that approximately 80% of obese adolescents become obese adults (12). The most compelling evidence comes from the Fels Longitudinal study, which followed 555 participants from age 1 to 18 years and assessed the same participants again at 35 years (13). This study demonstrated a strong relationship between elevated childhood BMI and adulthood obesity at age 35 years (13) and is in agreement with other studies showing that the probability of overweight increases with childhood age and BMI percentile level (14).

Secular trends and the role of early development

The Bogalusa Heart Study observed secular trends towards increased weight gain in a biracial rural group of children in two cohorts 11 years apart and showed that the weight gain was associated with dyslipidaemia and higher blood pressure suggestive of a greater cardiovascular risk in adolescents (15). There is also evidence to suggest that there has been a global decline of aerobic fitness of 0.36% per annum in 6- to 19-year-old youth in 27 countries over a 45-year period (1958–2003) (16). Although previous hypotheses center on the declines in energy expenditure to explain the rapid secular increases in obesity rates in the past few decades, scientific evidence does not necessarily support this notion as the sole mechanism for predictors of change in fat mass in children (17,18). Aerobic fitness, however, has been shown to predict longitudinal changes in adiposity in youth (18). Children and adolescents may be caught in a vicious cycle, in which physical inactivity is both a cause and a consequence of obesity. In essence, physical activity levels today are lower than decades ago, which may predispose youth to develop obesity, and obese children who are already physically inactive may remain inactive because of their excess weight and exercise intolerance among a multitude of other behavioural problems associated with obesity.

These secular changes demonstrate the importance of developing effective prevention initiatives in early development. Several hypotheses have evolved in attempt to explain the effect of the intrauterine environment and the maternal influence on early developmental origins of childhood obesity. Barker's 'thrifty phenotype' hypothesis (19), linking low birth weight with increased risk of developing type 2 diabetes mellitus and the metabolic syndrome in adulthood, has often been used to explain the fetal origins of disease onset in adulthood. The maternal-fetal environment has also been identified as a critical period for the development of obesity (1). This fetal programming hypothesis has recently garnered attention (20–26) but precise epigenetic mechanisms have yet to be established. Female adolescents are of particular concern given they are approaching child bearing age and longitudinal US data have identified young women at high risk for weight gain and obesity (27). Women of reproductive age should therefore be cautious because higher prepregnancy weight (14), excess gestational weight gain (28) and babies born large for gestational age (29) have been associated with greater risk of childhood obesity, perpetuating the intergenerational cycle of obesity across the lifespan (30).

What physiological changes occur during adolescence?

The adolescent phase is the period between childhood and adulthood (13–19 years), marked by changes in body composition, insulin sensitivity and growth during pubertal maturation.

Changes in body composition and insulin sensitivity

Adolescence is characterized by changes in quantity and location of body fat, which is part of the reason that it is a critical period for abnormal weight gain (1,12). Early adolescence is associated with a substantial increase in adipocyte (fat cell) size and number and the adolescent growth spurt is generally characterized by a rapid rate of growth in height (31). Once peak height velocity is achieved, rates of growth generally slow down and plateau until adulthood. Certain indicators of maturation including menarche (32), and peak height velocity (rate of change of height per unit of time) (33) have been associated with increased adiposity.

Body composition changes differ by sex throughout adolescence. Most studies in adulthood reveal that adult males have more central adiposity (abdominal region) especially visceral adipose tissue (fat between the organs), although females have more total adipose tissue and subcutaneous adipose tissue (fat beneath the skin) than males (34). From an evolutionary perspective, more body fat in females may have been favourable for healthy pregnancy. It has also been proposed that perhaps these sex differences become apparent once pubertal maturity is attained (35) given that sexual maturation does affect abdominal fat distribution and patterning in youth. Adolescent males and females show increases in fat-free mass whereas the percentage of body fat decreases for males and increases for females during maturation (31). The location of body fat deposition also differs between sexes. Male adolescents tend to deposit more fat in the abdominal subcutaneous region (beneath the skin) and the abdominal visceral depot (between the organs) whereas female adolescents distribute more fat peripherally, mainly in the hips (36), a similar pattern to that seen in adults. Girls undergoing puberty are at an increased risk of acquiring excess weight given adipocyte number in the subcutaneous gluteal (buttocks) region increases by 34% and adipocyte size by 45% in girls compared with similar-aged boys during adolescence (37–39).

The sex differences in adipose tissue distribution are likely caused by hormonal changes that occur during puberty (40). Estrogen typically drives the increase in adipose tissue deposition especially peripherally in females whereas testosterone is primarily responsible for the increase in fat-free mass in males. Furthermore, pubertal growth is associated with increases in growth hormone, which is known to increase rates of lipolysis in the liver, elevate circulation of free fatty acids and decrease insulin sensitivity. In fact, several studies have shown a ~30% decrease in insulin sensitivity during puberty for boys and girls (41–43), in lean and obese children alike (43), but the insulin resistance may worsen as the duration of obesity increases (44). It has been suggested that pubertal onset may be influenced by hyperinsulinaemia and insulin resistance since early menarche is preceded by increased insulin levels before puberty (45). Although many hypotheses have been proposed to explain the decrease in insulin sensitivity, precise mechanisms have not yet been established (46).

In view of the fact that insulin sensitivity typically decreases during adolescence and that increased levels of adiposity are strongly related to an increased likelihood of developing the metabolic syndrome (i.e. insulin resistance syndrome), overweight and obese adolescents are at an increased risk of developing cardiometabolic diseases. Obese children and adolescents are already presenting signs of adverse cardiometabolic consequences such as glucose intolerance, hyperinsulinaemia, dyslipidaemia, hypertension and the metabolic syndrome associated with their excess adiposity (47,48). This is of particular concern seeing as the prevalence of type 2 diabetes mellitus, previously known as adult onset diabetes, is now increasing at an alarming rate in obese youth (49).

Changes in pubertal maturation

Puberty can be defined as a complex developmental process characterized by maturation of the hypothalamic-pituitary-gonadal axis, the appearance of secondary sexual characteristics, acceleration of growth and the capacity of fertility (50). Age of menarche (first menstrual cycle), a convenient marker for the beginning of puberty in girls has decreased from 16 to 17 years in the 19th century to 13 years in the 20th century (51) and there is evidence that suggests early onset of menarche may be linked to the increased prevalence of obesity in today's society (52). In fact, three longitudinal studies show evidence to suggest that obesity precedes the onset of early puberty in girls (53–55).

Initiation and attainment of maximal growth spurt in adolescence typically indicates somatic maturation. The Penn State Young Women's Health Study showed that healthy white adolescent females aged 11–18 years experienced peak velocities for height, weight, total body fat and lean body mass at 12 years whereas most other tissues reached maximal growth at age 18 years (56). Children who mature earlier generally have a greater height, weight, adiposity and risk of becoming overweight and obese than those that are delayed in biological maturity, which persists throughout adolescence (31,45). Freedman et al. (2003) (32) also showed that obese girls mature earlier and attain menarche at an earlier age than leaner girls.

While obesity has been associated with earlier puberty in girls (31,32), the evidence is less clear on the relationship between obesity and the onset of puberty in males. One longitudinal German study (57) found that prepubertal body composition was not a critical determinant for the onset of puberty in 215 healthy boys and girls. In contrast, however, BMI and fat mass index predicted age at peak height velocity and duration of puberty in both sexes and age at menarche in girls (57). These results suggest that a greater BMI and fat mass ratio (fat mass/height^2) may increase the rate of pubertal maturation in boys and girls (57). Some other studies have linked obesity with later maturation in males (45), whereas the opposite is true for females. Males typically attain puberty approximately 2 years later than females (58).

Although there is some evidence to show that girls are nowadays maturing at an earlier age, the explanations behind the relationship between obesity and early sexual maturation warrant further investigation (59). Alongside the physical changes that occur with maturation, early-maturing girls and both very-early and later-maturating boys showed more evidence of psychopathology (60,61) evidenced by depression (61), substance abuse (62) and disordered eating (63). Girls exhibiting very early characteristics of sexual maturation also experience social stigma from their peers (64), and adolescents with overweight and obesity also suffer from weight bias and discrimination (65–67). Consciousness of body image and weight stigma has also been shown to negatively influence individuals' willingness to participate in physical activity (68).

What behavioural changes occur during adolescence?

Obesity is caused by an energy imbalance between energy intake (carbohydrates, fat and protein) and energy expenditure (resting metabolic rate, thermic effect of food and physical activity), and is continuously influenced by the obesogenic environment that we live in. There are several behavioural changes in dietary habits, physical and sedentary activity patterns that take place during adolescence that may influence the development and persistence of obesity.

Changes in diet

Between 1977 and 1996, consumption of food-away-from-home increased dramatically (69). Furthermore, consumption of fast foods (70) and sugar-sweetened beverages (71) have been associated with an increased risk of weight gain in adolescents. Energy intake increased by ~184 kcal d^{-1} among US children aged 2–18 years between 1977 and 2006 (72). It has been previously reported that only 1% of US children and adolescents meet all the requirements from the Food Guide Pyramid (73). In Canada, it has been shown that caloric consumption is greatest during adolescence and declines with age; where male adolescents reported 2800 calories and 2000 calories for female adolescents (74). The Canadian Community Health Survey observed that adolescents were not meeting Canada's Food Guide to Healthy Eating given that they report high consumption of 'other foods', total grams of fat, high frequencies of skipping breakfast and meal consumption away from home (74).

Although food and taste preferences are already present in early childhood, with the ever-changing environmental surroundings associated with the teenage years, the Bogalusa Heart Study showed that diet quality decreases from childhood to young adulthood in a sample of 246 young adults aged 19–28 years that completed a survey when they were 10 years old (75). The Norwegian Longitudinal Study that followed adolescents from age 14 to 21 years showed decreased fruit consumption and increased consumption of sweetened carbonated beverages in young adulthood (76). Another cohort study supports the findings that consumption of fruit, vegetables and milk decreased while the consumption of carbonated drinks increased from childhood to adolescence (77). Cross-sectional analyses reveal that consumption of dairy, grains, total fruit and vegetable intake are inversely correlated with central obesity in adolescents (78).

It is clear that there are several factors that affect food preferences in adolescents (79). Family meal frequency during adolescence has been positively associated with better meal quality and healthy meal patterns in young adulthood (80,81) and children who ate fewer family meals were more likely to become overweight (82). Adolescents who were more involved in meal preparation also consumed more healthful meals (83). Research has also shown that food preferences differ by age and sex. Males typically prefer nutritious meal-related comfort food whereas females and younger people (compared with those older than 55 years) prefer snack-related comfort food (84).

Obesity is commonly and inappropriately blamed solely on unhealthy lifestyles and lack of willpower of the individual; the environment in which we live plays a strong role in how our lifestyle behaviours are shaped and maintained. Interestingly, findings from focus groups in 141 adolescents in grades 7 and 10 suggest ways to help adolescents eat more healthfully by making healthful food taste and look better, limiting the availability of unhealthful options, making healthful food more available and convenient, teaching children proper eating habits early and changing social norms to make it 'cool' to eat healthfully (79).

Changes in physical activity

During the transition from childhood to adolescence, there is a steep decline in overall physical activity (85). Adolescents may also be at an increased risk of energy imbalance and abnormal weight gain because of their growth cessation and simultaneous declines in physical activity (40,86). Generally, physical education classes are mandatory in elementary school but not in high school, and physical activity often declines greatly during adolescence (86,87). In the United States, the 2009 Youth Risk Behaviour Surveillance found that only one-third of high school students grades 9–12 attended physical education classes daily and 81.6% of adolescents were not active for at least the recommended minimum of 60 min per day on all 7 days before the survey (88). The results of these surveys also demonstrated that students in younger grades and males were typically more physically active than students in older grades and females respectively. Other research supports that physical activity declines with age in both sexes but the declines are more pronounced in adolescent girls (86,89,90). Notably, an international review of physical activity levels between the ages of 10–17 years reported that boys are more active than girls whereas physical activity declines with age are more pronounced in girls (decreased by 7.4%) than in boys (decreased by 2.7%) (89).

Changes in fitness

Physical fitness levels among youth have declined worldwide in the past few decades (16,91). Substantial declines in aerobic and musculoskeletal fitness of Canadian children and youth have been observed from 1981 to 2007–2009 (92). As children age, absolute maximal oxygen uptake ($\dot{V}O_2 \max$, the best available indicator of aerobic fitness) increases at the same rate in both sexes until 12 years and continues to increase substantially until age 17–18 years in boys but remains relatively stable from age 14–18 years in girls (93). In pre-pubertal children, it has been shown that boys have 12–15% higher absolute $\dot{V}O_2 \max$ (L min^{-1}) than girls the same age with a greater difference seen after the age of 12 years (58). These sex differences in aerobic fitness are commonly seen in normal weight children especially between the ages of 11–13 years and 14–16 years (94). However, when evaluating obese adolescents, Berndtsson and colleagues (2007) (94) did not find significant sex differences in mass-related $\dot{V}O_2 \max$ ($mLO_2\ kg^{-1}\ min^{-1}$) between males and females. The authors attributed this lack of sex difference to the low participation in vigorous physical activity of obese boys.

It has been shown that aerobic fitness relative to body mass in obese adolescents is correlated with free-living physical activity and inversely related with percent body fat (95). The Quebec En Forme Project also showed a negative correlation between BMI, waist circumference and measures of physical fitness (standing long jump, 1-min speed sit-ups and speed shuttle run), which became more pronounced with age (90). Furthermore, several other studies found negative correlations between body fat, running speed and endurance shuttle run tests (96,97). Kimm et al. (2005) (98) suggested that low fitness may play an important role in the development of obesity in girls. In short, physical fitness has declined in the last two decades and physical activity levels decline substantially with age, especially in girls. The predominant sex differences in body composition, growth and physical activity behaviours ignite the potential interest in developing sex-specific and more individualized interventions in obese youth.

Furthermore, Canadian epidemiological studies have shown substantial declines in adolescent sport participation from 1992 (77%) to 2005 (59%), (99) which are paralleled by the declines in physical fitness observed from 1981 to 2009 (92). Obese youth tend to participate less in structured organized sport than non-obese children especially when comparing obese boys with non-obese boys (97). Moreover, it has been estimated that only half of Canadian youth aged 12–17 years are classified as 'active' in their habitual leisure time (99).

Changes in sedentary activity

In light of the significant changes in physical activity described earlier, it is not surprising that only 7% of youth meet Canada's physical activity guidelines of 60 min per day (92,100) and are spending more time doing sedentary activities. Sedentary activity has been linked to all-cause and cardiovascular disease mortality (101,102). Today's youth spend more time engaged in sedentary behaviours requiring minimal movement such as sitting, lying down, playing video and computer games. In 1988, adolescents reported watching 9 h of TV per week (7). In 2004, time spent in front of a TV increased to 10 h but when video games and time spent in front of a computer were factored in the equation, adolescents spent 20 h per week in sedentary activity (7).

It has also been shown that the transition from childhood to adolescence is associated with significant increases in sedentary activity (103). More exposure to screen time (i.e. TV, internet, video games) has been linked to consuming unhealthy snacks (104), increasing the likelihood of developing the Metabolic Syndrome (105) and interference with normal sleep patterns (106,107) where short sleep duration has also been associated with obesity (108,109). Secular trends have shown a decrease of over 1 h per night of sleep duration in children and adolescents across 20 countries from 1905 to 2008 (110). It has been shown that sleep duration on weekdays decreases during early to late adolescence but increases on the weekends to compensate for the loss during the week (111). A recent German study also showed that adolescents sleep less than the recommended 9 h of sleep on weekdays (112). Sleep can influence the secretion of hormones that play roles in energy metabolism. Some studies have also shown that sleep restriction can lead to decreased circulating levels of leptin and increased ghrelin (113), and these hormone levels have been associated with increased BMI (113), increased appetite and food intake (114).

Several mechanisms have been proposed to explain the association between sedentary activity and adverse health outcomes such as the reduction of available time for physical activity (115), reduced metabolic rate (116), increased energy intake (117), and the influence of media advertisements promoting unhealthy food and beverage choices (118). In fact, exposure to media television food advertisements has increased in adolescents (119) and the American Academy of Pediatrics (AAP) recently published a policy statement cautioning health care professionals to monitor sedentary activity in youth because of these well-known adverse health consequences (120).

The AAP states that there are several other factors that influence the declining physical fitness trend in today's children and youth (121). A review by Sallis et al. (2000) (122) reports that several variables are strongly positively related to physical activity in adolescents including male sex, white ethnicity, parental support, support from others, sibling physical activity, perceived activity competence, intention to be active, sensation seeking, previous physical activity, community sports and opportunities to exercise. In addition, age, depression and time spent in sedentary activity after school and on weekends were inversely related to physical activity.

The pursuit of further education and/or entry into the workforce may be another avenue that warrants further investigation of changes in weight and adiposity during the transition from adolescence to adulthood. It is well-established that the college years are associated with weight gain and males typically gain more weight than females during this period (123,124). Contrary to popular belief, however, the media portrayal of 'the freshmen 15' (125) is an exaggeration of the weight gain that may occur during the first year of college. A meta-analysis of 24 studies based on a pooled sample of 3, 401 cases showed an average weight gain of 3.86 (95% confidence intervals = 3.81–3.91) pounds (126). Furthermore, a more recent study investigating the US National Longitudinal Survey of Youth showed that freshmen gained an average of 2.5 to 3.5 lb (instead of the misconstrued 15 lb) during their first year of college although they continued to gain weight throughout their college years (127). This study, however, showed that going to college had little to do with gaining weight; the college freshman gained only 0.5 lb more than their counterpart who did not go to college (127). One study investigated the beliefs about weight gain and observed sex differences that could contribute to difficulties in engaging young adults in intervention programs. They showed that women were more interested in weight control programs whilst men were disinterested in weight gain prevention programs regardless of weight status and were less concerned about gaining weight than females (128). With regards to entry into the workforce, one recent study examining young female adults suggested that more time spent at work could contribute to further weight gain in young women (129). The Australian Longitudinal Study of Women's Health 4-year follow-up study also showed that life transitions of getting married, having children, and starting work were associated with decreased levels of physical activity in young adult women (130). Future studies should examine these transitions and evaluate the effectiveness of college and work force interventions designed to promote healthy active living for obesity prevention and management in adolescents transitioning to adulthood.

Sociodemographic and psychosocial contributors and consequences

There is a large international variation in the association between low socioeconomic status (SES) and obesity prevalence worldwide (131). Despite increases in the prevalence of overweight in American adolescents between 1971 and 2002 in both low and high SES, nationally representative data showed that the relationship between SES and obesity is not straightforward and differs by age, sex and race in the United States (132). The authors also showed that the strength of the association between SES and overweight decreased over time although ethnic disparity increased especially in adolescent girls (132). Furthermore, the highest prevalence of extreme obesity (BMI ≥ 1.2 x 95% or ≥99% for age and sex) is observed in Hispanic and African–American children (133). The role of socioeconomic, geographic and environmental factors should be underscored and efforts should focus on all SES groups as well as targeting some high risk ethnic minority groups (132).

Gender, race and ethnicity are also important factors to consider when evaluating the mental health, body satisfaction and weight status of adolescents. Strong evidence supporting greater body dissatisfaction and patterns of disordered eating in girls compared with boys (134) has instilled the importance of catering to the needs of young women with weight issues (135,136). Overweight white and Hispanic youth were more likely to be reported by their parents as suffering from mental health problems such as depression or anxiety, lower self-worth, behavioural problems and bullying others than their non-overweight peers (137). Although the majority of studies report lower expression of body dissatisfaction in African–American girls compared with white girls (138), more literature is emerging showing patterns of disordered eating and body dissatisfaction in Hispanic Latinas and Native American adolescents (139). Furthermore, likelihood of self- perception of overweight status was found to be higher in females, whites, and in individuals with greater BMI, greater income and higher education (140).

Social networks and peer relationships can influence adolescents' lifestyle choices and behaviours where friendships are usually formed around shared behaviours. It has been shown that overweight youth aged 11–15 years were twice as likely to have overweight friends, and overweight girls were less likely to be named as a friend than normal weight girls (141). Social marginalization is also highly prevalent in overweight adolescents. A cross-sectional analysis of the National Longitudinal Study of Adolescent Health examined the impact of overweight on friendship networks and found that overweight adolescents received fewer friendship nominations from others compared with their normal weight peers (142). Moreover, many obese adolescents endure considerable weight-based teasing and bullying, which exacerbates social marginalization/alienation and is associated with increased psychological distress (143). In turn, these can often lead to emotional eating or binge eating and further weight gain in adolescents (66). However, increased participation in sports and school clubs and decreased TV viewing were factors related to increased friendship nominations in both overweight and normal weight adolescents (142). Thus, if overweight adolescents pursue these activities to expand their social networks, they should also be taught how to cope with the possibilities of weight-based teasing or bias that may occur in these pursuits.

Other studies have also looked at the influence of assortative mating (obese individual preferring to mate with another obese individual) (144) on the development of childhood obesity, yet more research is warranted. Such observations may be indicative of the effect of social networks on obesity and how these may be amplified during the critical period of adolescence. While nutrition and physical activity are important in achieving optimal health, programs, interventions, and policies should address psychosocial factors that contribute to overweight or obesity (145). Poor nutrition and inadequate physical activity may be the result of psychosocial contributors to, or secondary morbidities associated with obesity (146). Affected youth may suffer psychosocial consequences, such as bullying, depression, low self-esteem, and weight bias, which may make it even more difficult to manage their weight (147). Moreover, it has been reported that obese adolescents report the same quality of life than that of peers undergoing chemotherapy treatment for cancer (148).

Adolescence also encompasses a period of time where participation in high-risk behaviours becomes more common (88). One important psychological contributor is stress, which may lead to emotional eating or overeating whereby youth use food as a coping mechanism. Sources of stress in obese youth often include being bullied, having poor self-esteem or social skills, and also being the victim of weight teasing and discrimination and parental separation and divorce (149,150). Adolescents of lower socio-economic class and who attend schools and live in countries of larger economic inequality have a higher prevalence of bullying victimization (151). Stress may impact obesity in youth in several other ways. For example, chronic stress may interfere with adequate sleep duration and quality, which have been shown to be risk factors for obesity in youth (152). Stress may also negatively affect the immune system, by stimulating neuro-endocrine responses. The hypothalamic pituitary axis (together with the sympathetic nervous system) may then predispose one to accumulating intra-abdominal adiposity, insulin resistance and the metabolic syndrome via excessive cortisol production in response to stress (153).

Depressive disorders occur earlier in life (154) than in the past, and the prevalence of depression in teens is almost twice as high as adults aged 25 to 44 years (155). In addition to the adverse physiological adaptations associated with obesity, overweight and obese youth are more likely to experience depression compared with their normal weight peers (156). Girls are especially at risk of depression if they are concerned about their weight (157). Furthermore, adolescents that experience depression are at an increased risk of the development and persistence of obesity (158). In fact, the 1996 National Longitudinal Study of Adolescent Health in grades 7–12 reports that the negative psychosocial effects of childhood obesity are linked to a poor physical quality of life (functional limitations and illness symptoms) (159).

Adolescence is a developmental period in which body weight and shape undergo considerable changes, which often precipitates self-consciousness and insecurity about youth's body habitus. Thus it is not surprising that one reliable correlate of obesity in youth is body dissatisfaction. The social stigma associated with obesity is believed to engender shame, guilt and intense feelings of body dissatisfaction (160). This is clinically significant because body dissatisfaction is not only an untoward

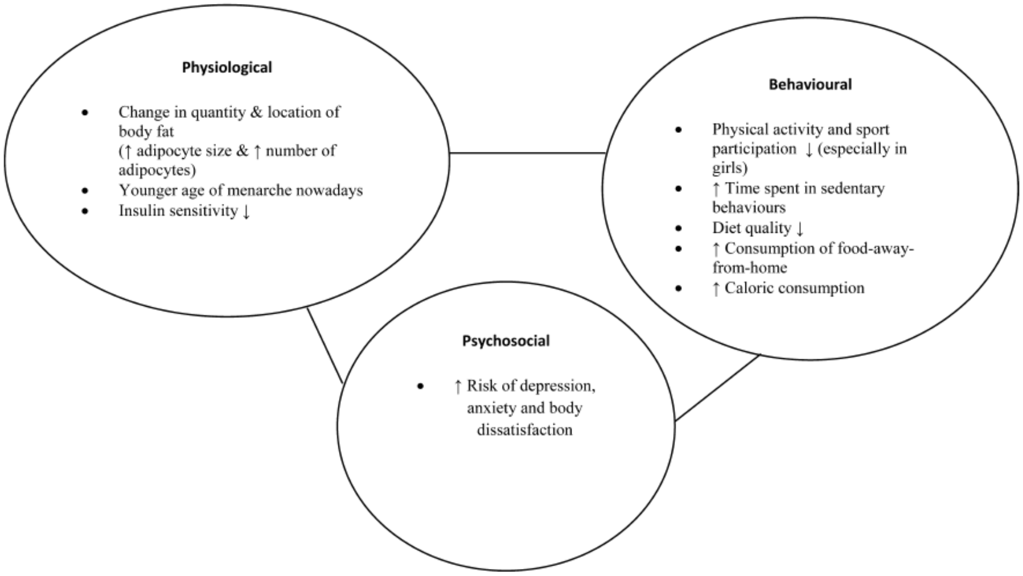

Figure 1 Changes that occur during adolescence that may increase the risk of obesity.

consequence of obesity, a negative body image also serves as the impetus to engage in strict dieting and unhealthy eating and weight control practices. Despite the increase in obesity, the desire to be lean and have well-toned muscles for both adolescent males and females is widespread, resulting in an increase in dieting to achieve societal beauty standards (161). Dietary restraint, the conscious restriction of calories to control body weight, is well documented to be a risk factor in the development and maintenance of binge eating and eating disorders (162), has been associated with obesity (163) and is predictive of future weight gain in youth (164,165).

Summary

Current research demonstrates that the adolescent period is marked by critical changes in body composition, insulin sensitivity, physical activity, sedentary and diet behaviours, and psychological issues that that make adolescents at an increased risk of becoming overweight and maintaining obesity in adulthood (Fig. 1). Physical activity, sport and physical education participation decrease during adolescence, especially in girls. Despite increasing awareness, adolescents are constantly confronted with external factors in our obesogenic environment that favour unhealthy behaviours. As BMI and physical activity habits track strongly from youth to adulthood and this relationship strengthens with age, it is important to establish healthy behaviours *early* in the lifespan to prevent the onset of childhood and adolescent obesity. The strong evidence found in childhood obesity tracking studies proves the necessity of intervening early in the lifespan and changing our environment to deter from the propagation of the deleterious effects of adulthood obesity and associated co-morbidities.

Conflict of Interest Statement

No conflict of interest was declared.

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MANUSCRIPT 2: A Review of Aerobic Exercise Training in Obese Adolescents

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Permission was granted to include the published version of this article in this dissertation (Appendix).

Statement of contributions of collaborators:

A.S. Alberga conceived the topic and content of this review article, carried out the bibliographic search, article screening**,** evaluated the evidence and drafted and edited the manuscript. A. Frappier assisted with the bibliographic search, article screening, and assisted in the drafting and editing of the manuscript. R.J. Sigal, D. Prud'homme and G.P. Kenny provided analytical input and helped draft and edit the manuscript.

A Review of Randomized Controlled Trials of Aerobic Exercise Training on Fitness and Cardiometabolic Risk Factors in Obese Adolescents

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Abstract: Aerobic training is the most prescribed exercise modality for the management of pediatric obesity. There is strong evidence that it decreases waist circumference, percent body fat and visceral fat, increases cardiorespiratory fitness, and decreases blood pressure in obese adolescents. However, the independent effects of aerobic exercise training on other cardiometabolic risk factors (ie, insulin resistance markers, plasma lipid levels, and inflammatory markers) are limited and yield inconsistent findings. Our article reviews randomized controlled trials evaluating the effects of aerobic exercise training on body composition, fitness, lipid levels, and insulin resistance in obese adolescents (aged 13–18 years) and outlines future research directions for this population.

Keywords: aerobic training; exercise; obesity; adolescents; plasma lipid levels; insulin resistance

Introduction

Adolescence has been described as a critical period for the onset and development of obesity throughout the lifespan.[1,2] The prevalence of adolescent obesity in Canada doubled from 14% in 1978 to 1979, to 29% in 2004,[3] while sport participation[4] and fitness levels[5] of Canadian youth have declined substantially. Adolescents with obesity have poorer fitness compared with their non-obese peers[6] and have a higher risk for developing type 2 diabetes mellitus (T2DM).[7] Obese adolescents may particularly benefit from increased physical activity to improve their overall health and quality of life.

Higher levels of cardiorespiratory fitness or aerobic fitness, typically linked with performing aerobic exercise regularly, are associated with reduced risk of cardiovascular disease[8] (CVD) and premature mortality[9] in obese and non-obese adults. Aerobic exercise training (including walking, cycling, jogging, skipping, or swimming), defined as continuous movement involving rhythmic contraction of large muscle groups over time, has been the most traditionally prescribed exercise modality for individuals with obesity. Randomized controlled trials of aerobic exercise interventions in adults have shown improvements in body composition,[10] lipid profiles, blood pressure, glycemic control,[11] and cardiorespiratory fitness,[12] although data showing similar improvements are not as clear in adolescents aged 13 to 18 years. Strong scientific evidence is lacking on the effects of aerobic training in reducing cardiometabolic risk factors in obese adolescents.

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Our article reviews the effects of aerobic exercise on body composition, fitness, and cardiometabolic risk factors in obese adolescents as found in clinical trial data. We focus on data from randomized controlled trials that incorporated an aerobic training–only group in adolescents (aged 13–18 years) with obesity, unless otherwise stated. We searched the databases of Embase, Sportdiscuss, and Medline/PubMed for potentially relevant articles with the keywords: *exercise, aerobic, physical training, systolic blood pressure* (SBP), *diastolic blood pressure* (DBP), *blood pressure* (BP), *inflammation, inflammatory markers, C-reactive protein, interleukin-6* (IL-6), *tumor necrosis factor-alpha* (TNF-α), *triglycerides, total cholesterol, low-density lipoprotein* (LDL-cholesterol [C]), *very–low-density lipoprotein, high-density lipoprotein* (HDL-cholesterol [C], *blood lipids, insulin, insulin resistance, insulin sensitivity*, and *glucose*. English- or French-language studies published after 1975 were considered. Studies had to include and describe an aerobic exercise prescription to be included in our review. Although there was no minimum exercise intervention length required for inclusion, studies had to describe the exercise program prescription (frequency, intensity, duration, and type). Many articles were extracted from Embase (1105 articles), SPORTDiscus (102 articles), and Medline/PubMed (452 articles) but only 17 articles met all the criteria for review. Studies were excluded if the only modality prescribed was a combination of both aerobic and resistance training. Precise exercise program details and main outcomes of the studies we reviewed are shown in Table 1.

Effects of Aerobic Exercise Training on Body Composition

Adolescents with obesity are at a greater risk for cardiometabolic disease compared with their leaner peers.[13] Obese adolescents enrolled in aerobic exercise training trials have shown changes in body weight from +0.3 to –11.5 kg,[14–17] –0.3 to –3.9 kg/m^2 in body mass index (BMI),[13–19] and –0.28 to –6.3% in percent body fat.[13–21] It is difficult to isolate the commonalities among studies that favor success because the studies did not all use the same exercise prescription or the same method of assessing body fat. Some of these studies used well-validated body composition measurement techniques,[19,21–22] including dual-energy x-ray absoptiometry (DEXA), magnetic resonance imaging (MRI), underwater weighing, or computed tomography, whereas most of the studies used lower-quality methods,[13–18,23–24] such as skinfold thickness and bioelectrical impedance. The largest improvement observed in percent body fat (–6.3%) assessed by DEXA was reported by Bagalopal et al,[21] who randomized 15 post-pubescent obese adolescents to either a lifestyle intervention program or usual care for 3 months. The lifestyle intervention program included 45 minutes of brisk walking 3 times weekly for 3 months. The lifestyle intervention group showed a decrease in percent body fat from 45.5 ± 2.3% to 39.2 ± 2.3% ($P < 0.01$) with an increase in fat-free mass from 57.3 ± 3.8 kg to 63.6 ± 4.1 kg ($P < 0.01$). However, the independent effects of exercise from this study are unclear because of the small sample size, the lack of exercise program details, and the concomitant dietary restriction and behavioral counseling that were also included in the lifestyle intervention. Two other randomized controlled studies showed moderate decreases in percent body fat (–3.6%[16] and –3.57%[22]) following combined lifestyle education programs with moderate exercise intensity (55% to 80% of peak rate of oxygen consumption [$VO_{2\text{ peak}}$]) 5 to 6 days weekly after 3 months and 8 months, respectively. Despite the short 6-week duration, Kim et al[14] also showed that an intensive jump-rope program of 60 jumps per minute for 40 minutes per session, 5 days per week, decreased percent body fat (from 31.5% ± 1.0 to 29.3% ± 1.0; $P < 0.05$).

The location of excess body fat deposition, especially in the abdominal region, warrants more attention for chronic disease prevention than the quantity of total body fat.[25] Although ≥ 25% body fat has been associated with greater relative risk of CVD mortality and all-cause mortality in adults,[8] greater waist circumference (≥ 88 cm for women and ≥ 102 cm for men)[26] and higher levels of visceral fat (fat surrounding the organs > 130 cm^2)[27] are associated with greater risk of T2DM and CVD in adults.[28] Visceral, subcutaneous abdominal, and liver fat are associated with a higher mortality risk, but visceral fat is an independent predictor of mortality risk in men, after adjusting for the other fat measures.[29] The relationship of increased visceral fat with prediabetes and CVD risk factors is already present in childhood and adolescence.[30–31] Aerobic exercise training interventions in obese adolescents have shown reductions in waist circumference,[6,14,16,19,23–24,32] although only 3 studies have measured visceral fat,[22,32–33] and 2 of the studies' data showed decreases in the participants' central region following aerobic training.[22,32] Although this has yet to be revealed with obese adolescents, studies using aerobic exercise interventions in obese adults showed that reductions in visceral fat and cardiometabolic risk can occur with minimal or no changes in body weight.[10,34] This is an important finding that highlights the fact that aerobic exercise training has the potential to reduce visceral adiposity

Table 1. Randomized Controlled Trials Including an Aerobic Exercise Training Component in Obese Adolescents

Source	**Sample Age (y), N**	**BMI, kg/m^2**	**Comparator Groups**	**Exercise Program Details**				**Results From the Exercise Groups (P = NS, unless otherwise noted)**	
				Type	**Duration**	**Intensity**	**Frequency per week**	**Changes in body composition and fitness**	**Changes in cardiometabolic risk factors**
Balagopal et al[21]	~16 21	> 30	CON lean (n = 6) CON ob (n = 7) LIFE + DIET + EX (n = 8)	Brisk walking	3 mo, 45 min/ session	Moderate	3x	Weight: –0.3 kg % BF: –6.3%^{a,b}	LDL/HDL: –28%^{a} CRP: –30%^{a} IL-6: –25%^{a} HOMA-IR: –24%^{a,b}
Ben Ounis et al[23]	12–14 24, males	> 97th percentile	DIET (n = 8) EX LIPOX (n = 8) DIET + EX (n = 8)	Running, jumping, playing with a ball	2 mo, 90 min/ session	HR corresponding to LIPOX$_{max}$	4x	EX LIPOX Weight: –1.9 kg BMI: –0.8 kg/m^2 Waist: –1.8 cm Fat mass: –1.7 kg DIET + EX Weight: –11.5 kg^{a} BMI: –3.9 kg/m$^{2\,a}$ Waist: –12.3 cm^{a} Fat mass: –11.2 kg^{a}	EX LIPOX: TG: –0.13 mmol/L^{a} TC: –0.21 mmol/L HDL: +0.06 mmol/L^{a} LDL: –0.21 mmol/L LDL/HDL: –0.33^{a} TC/HDL: –0.42^{a} HDL-C:TG: +0.12^{a} Fasting glucose: –0.02 Fasting insulin: –5.1 µU/mL^{a} HOMA-IR: –1.06^{a} DIET+EX: TG: –0.24 mmol/L^{a} TC: –0.51 mmol/La HDL: +0.15 mmol/L^{a} LDL: –0.55 mmol/L^{a} LDL/HDL-C: –0.84^{a} TC/HDL: –1.03^{a} HDL-C:TG: +0.25^{a} Fasting glucose: –0.32 mmol/L^{a} Fasting insulin: –9.4 µU/mL^{a} HOMA-IR: –2.13^{a}
Ben Ounis et al[24]	12–14, 32	> 97th percentile	CON (n = 16) EX (n = 16)	Running, jumping, playing with balloon	8 wks, 90 min/ session	66% of VO_{2peak}	4x	Weight: –4.7 kg^{a} BMI: –1.9 kg/m$^{2\,a}$ Waist: –8 cm^{a} Fat mass: –2.8 kg^{a} $VO_{2\,peak}$: +16.3%^{a}	SBP: –11.6 mm Hg^{a} DBP: –8.9 mm Hg^{a} TG: –25.7 mg/dL^{a} HDL-C: +6.6 mg/dL^{a} Fasting glucose: –10.6 mg/dL^{a}
a. Gutin et al[22]	13–16, 80	> 85th percentile	LIFE alone (n=19) LIFE + MOD PT (n=21) LIFE + HIGH PT (n=21)	Aerobic machines, aerobics, basketball, badminton, kickball, and aerobic slides	8 mo, Moderate-intensity group: 43 min/ session High-intensity group: 29 min/ session	Moderate = 55%–60% of $VO_{2\,peak}$ High = 75%–80% of $VO_{2\,peak}$	5x	PT GROUPS COMBINED (a): VAT: –42 cm$^{3\,b}$ % BF: –3.57%^{b} Fat mass: –0.73 kg VO_{2max}: +1.72 mL O_2/kg/min^{b} MOD PT GROUP (b): % BF: –1.42% VAT: –49.0 cm^3 VO_2-170: +2.27 mL O_2/kg/min	PT GROUPS COMBINED (a and c): CRP: value N/A

(Continued)

Table 1. (*Continued*)

Source	Sample Age (y), N	BMI, kg/m^2	Comparator Groups	Exercise Program Details				Results From the Exercise Groups (*P* = NS, unless otherwise noted)	
				Type	Duration	Intensity	Frequency per week	Changes in body composition and fitness	Changes in cardiometabolic risk factors
b. Kang et al[35]								HIGH PT (b): % BF: −2.85% VAT: −48.73 cm^3 VO$_2$-170: +4.69 mL O$_2$/kg/min^b	MOD PT GROUP (b): SBP: −2.05 mm Hg DBP: −3.75 mm Hg TC: +0.03 mmol/L HDL: 0.00 mmol/L TC/HDL mod: +0.13^b VLDL: −0.01 mmol/L LDL: −0.15 mmol/L Fasting glucose: +0.40 mmol/L Fasting insulin: +21.18 pmol/L
c. Barbeau et al[20] (All 3 papers [a, b, and c] are published from the same sample of study participants.)									HIGH PT GROUP (b): SBP: −6.15 mm Hg DBP: −5.92 mm Hg^b TC: +0.01 mmol/L HDL-C: −0.02 mmol/L TC/HDL-C: +0.05^b VLDL: −0.08 mmol/L LDL-C: −0.02 mmol/L Fasting glucose: +0.31 mmol/L Fasting insulin: −14.21 pmol/L
Kim et al[14]	~17, 26	29.5 ± 2.2	CON lean (n = 14) CON ob (n = 12) EX ob (n = 14)	Jump rope	6 wks, 40 min/ session	60–90 jumps/min	5x	Weight: −2.2 kg^a BMI: −1.0 kg/m$^{2\,a}$ Waist: −2.5 cm^a % BF: −2.2%^{a}	SBP: −0.7 mm Hg DBP: +2.1 mm Hg TC: −4.0 mg/dL TG: −33.6 mg/dL^a HDL-C: −0.3 mg/dL LDL-C: + 3.0 mg/dL CRP: −0.07 mg/mL TNF-α: +0.18 pg/mL IL-6: +0.05 PG/mL Fasting insulin: −4.1 µU/mL^a HOMA-IR: −0.83^a
Lee et al[6]	~17, 38, females	≥ 25	CON lean (n = 20) CON ob (n = 7) EX (n = 11)	Rope skipping	12 wks, 40–50 min/ session	60%–80% of HR$_{max}$	4x	Weight: −2.56 kg^{a,b} BMI: −1.11 kg/m$^{2\,a,b}$ Waist: −6.13 cm^{a,b} % BF: −1.37%^{b} VO$_{2\,peak}$: +2.51 mL O$_2$/kg/min^{a,b}	TC: −18.09 mg/dL^a TG: −30.18 mg/dL^a HDL-C: +2.28 mg/dL Fasting glucose: +4.81 mg/dL^a Fasting insulin: −6.61 µU/mL^a HOMA-IR: −2.0^a
Lee et al[32]	12–18, 45, males	≥ 95th percentile	CON (n = 13) AEROBIC (n = 16)	AEROBIC: Treadmill, elliptical, or stationary cycling	3 mo, 60 min/ session	AEROBIC: 40 min at 50% VO$_{2\,peak}$ progressed to 60 min at 60%–75% of VO$_{2\,peak}$	3x	AEROBIC Weight: −0.04 kg^b BMI: −0.3 kg/m^2 Waist: −2 cm^b % BF: −2.6%^{b} VAT: −0.1 kg^b	AEROBIC: Fasting glucose: −0.4 mg/dL Fasting insulin: −18.0 µU/mL First-phase insulin: 3.9 µU/mL

(*Continued*)

Table 1. *(Continued)*

Source	Sample Age (y), N	BMI, kg/m^2	Comparator Groups	Exercise Program Details				Results From the Exercise Groups (P = NS, unless otherwise noted)	
				Type	Duration	Intensity	Frequency per week	Changes in body composition and fitness	Changes in cardiometabolic risk factors
								VO$_{2\,peak}$: +9.1 mL O$_2$/kg/min^b	Second-phase insulin: −36.2 µU/mL Insulin sensitivity: 0.4 mL/kg/min per µU/mL
			RESISTANCE (n = 16)	RESISTANCE: 10 whole-body exercises using stack weight equipment		RESISTANCE: 1–2 sets of 8–12 reps at 60% of 1 rep maximum progressed to 2 sets of 8–12 reps to fatigue		RESISTANCE: Weight: −0.6 kg^b BMI: −0.6 kg/m$^{2\,b}$ Waist: −3.2 cm^b % BF: −2.5%^{b} VAT: −0.2 kg^b VO$_{2\,peak}$: +7.7 mL O$_2$/kg/min^b	RESISTANCE: Fasting glucose: 0.1 mg/dL Fasting insulin: −10.4 µU/mL First-phase insulin: −38.2 µU/mL Second-phase insulin: −48.6 µU/mL Insulin sensitivity: 0.8 mL/kg/min per µU/mL^b
Meyer et al[13]	11–16, 102	CON lean: 18.6 ± 2.02 CON ob: 31.0 ± 4.42 EX: 29.8 ± 5.93	CON lean (n = 35) CON ob (n = 34) EX (n = 33)	Swimming, sports games	6 mo, 1–1.5 h/session	Progressively intensified as individually tolerated	3x	BMI: −2.6 kg/m$^{2\,a}$ % BF: −1.0%	SBP: −8 mm Hg^a TG: −0.37 mmol/L^{a,b} LDL-C: −0.14 mmol/L^{a,b} HDL-C: −0.01 mmol/L LDL-C/HDL-C: −0.13 CRP: −2.79 mg/L^{a,b} Fasting insulin: −2.64 pmol/L^{a,b} HOMA-IR: −0.82^{a,b} HbA$_{1c}$: 0.0
Nemet et al[15]	6–16, 46	28.5 ± 4.1	CON DIET (n = 22) EX + DIET (n = 24)	Activities	3 mo, 1h/session	Intensity elementary/high school children perform normally	2x	Weight: −2.8 kg^a BMI: −1.7 kg/m$^{2\,a}$ % BF: −3.3%^{a}	TG: −13.9 mg/dL TC: −22.3 mg/dL^b HDL-C: +1.2 mg/dL LDL-C: −16.8 mg/dL^b
Park et al[16]	13–15, 44, females	≥ 95th percentile	CON (n = 22) LIFE + EX (n = 22)	Walking	12 wks, 30–40 min/session	55%–75% of aged-predicted HR$_{max}$	6x	Weight: −4.3 kg^b BMI: −1.9 kg/m$^{2\,b}$ Waist: −4.7 cm^b % BF: −3.6%^{b}	SBP: −6.5 mm Hg^b DBP: −2.2 mm Hg TC: −9.7 mg/dL^b HDL-C: −0.1 mg/dL LDL-C: −10.7 mg/dL^b TC/HDL-C: −0.2 mg/dL^b CRP: −0.2 mg/L^b Fasting glucose: −8.8 mg/dL^b Fasting insulin: −3.4 µU/mL^b HOMA-IR: −1.0^b HbA$_{1c}$: −0.1%
Rocchini et al[38]	10–17, 73	> 75th percentile	CON lean (n = 10) CON ob (n = 18) DIET (n = 22) DIET + EX (n = 23)	Walking, jogging	20 wks, 60 min/session	70%–75% HR$_{max}$	3x	Weight: −2.4 kg^{a,b} % BF: −6%^{a,b}	SBP: −13 mm Hg^{a,b} DBP: −21 mm Hg^{a,b}

(Continued)

Table 1. *(Continued)*

Source	Sample Age (y), N	BMI, kg/m^{2}	Comparator Groups	Exercise Program Details				Results From the Exercise Groups (*P* = NS, unless otherwise noted)	
				Type	Duration	Intensity	Frequency per week	Changes in body composition and fitness	Changes in cardiometabolic risk factors
Rosenbaum et al[18]	~13, 73	~24	CON (n = 24) EX (n = 49)	Dance, kickboxing	3–4 mo, No time reported	N/A	3x	Weight: –0.1 kg, NS BMI: –0.7 kg/m^{2}[a] % BF: 1.3%[a]	TC-C : +0.05 mmol/L TG-C: –0.05 mmol/L HDL-C: –0.02 mmol/L LDL-C: +0.1 mmol/L CRP: –1.12 pg/mL[a,b] TNF-α: +0.01 pg/mL IL-6: –0.3 pg/mL[a] Fasting glucose: –0.01 mmol/L Fasting insulin: –7.0 pmol/L QUICKI: –7 pmol/L[a]
Savoye et al[17]	8–16, 209	> 95th percentile	CON (n = 69) LIFE + EX (n = 140)	Games, obstacle courses, flag football, etc.	12 mo, 50 min/session	65%–80% of age-predicted HR$_{max}$	2x	At 6 months: Weight: –2.6 kg[b] BMI: –2.1 kg/m^{2}[b] % BF: –3.2%[b] At 12 months: Weight: +0.3 kg[b] BMI: –1.7 kg/m^{2}[b] % BF: –4.0[b]	At 6 months: SBP: –2.2 mmHg DBP: –1.7 mmHg TC: –7.5 mg/dL[b] HDL-C: +2.2 mg/dL LDL-C: –3.3 mg/dL TG: –17.9 mg/dL Fasting glucose: –2.2 mg/dL Fasting insulin: –6.5 µU/mL[b] HOMA-IR: –1.51[b] At 12 months: SBP: –2.0 mm Hg DBP: +1.4 mm Hg TC: –9.2 mg/dL[b] HDL-C: +3.2 mg/dL LDL-C: –2.4 mg/dL TG: –2 1.3 mg/dL Fasting glucose: –3.4 mg/dL Fasting insulin: –6.1 µU/mL[b] HOMA-IR: –1.52[b]
Suh et al.[33]	~13.10, 30	> 85th percentile	Diet only (n = 10) Aerobic EX + DIET (n = 10) Resistance EX + DIET (n = 10)	Jumping rope, walking or running on a treadmill, and stationary cycling	12 wks, 40 min/session	60%–70% of VO$_{2\,max}$	3x	Weight: –0.61 NS BMI: –0.45 kg/m^{2}[a] Waist: –0.76 cm % BF: –0.28% VAT: –0.94 cm^{2}	N/A
Tjonna et al[19]	~14, 54	AIT (33.2 ± 6.1) LIFE (33.3 ± 4.5)	AIT (n = 28) LIFE (n = 26)	Walking/running uphill	AIT: 3 mo, 40 min/session LIFE: 12 mo	4 x 4 min intervals at 90%–95% HR$_{max}$ with 3 min active recovery at 70% HR$_{max}$	2x	At 12 months: Weight: +0.3 kg BMI: –1.8 kg/m^{2} Waist: –7.2 cm[a] % BF: –2.0%[a]	At 12 months: SBP: –7.9 mm Hg[a] DBP: –4.9 mm Hg[a] HDL-C: +0.11 mmol/L TG: –0.24 mmol/L Insulin: –62.6 pmol/L[a] Insulin (2 h glucose dose): –340.4 pmol/L)[a]

(Continued)

Table 1. *(Continued)*

Source	Sample Age (y), N	BMI, kg/m^2	Comparator Groups	Exercise Program Details				Results From the Exercise Groups (P = NS, unless otherwise noted)	
				Type	Duration	Intensity	Frequency per week	Changes in body composition and fitness	Changes in cardiometabolic risk factors
								VO_{2peak}: +3.7 mL O_2/kg/min[a,b]	Fasting insulin: −0.3 mmol/L[a] HOMA2-%S: +17.6[a] HbA_{1c} (%): −0.015

[a] Significantly different from pre- to post-intervention (within-exercise group only).

[b] Significantly different from control group.

Abbreviations: AIT, aerobic interval training; BF, body fat; BMI, body mass index; CON, control; CRP, C-reactive protein; DBP, diastolic blood pressure; DIET, caloric limits; EX, exercise; HDL-C, high-density lipoprotein cholesterol; HDL-C:TG, ratio of high-density lipoprotein cholesterol to triglycerides; HOMA-IR, homoeostatic model assessment index for insulin resistance; HOMA2-%S, homeostasis model assessment index for insulin sensitivity in percent (100% is considered normal); HR, heart rate; IL-6, interleukin-6; LDL-C, low-density lipoprotein cholesterol; LIFE, lifestyle intervention; $LIPOX_{MAX}$, maximal rate of lipid oxidation; MOD, moderate; N/A, not available; NS, not significant; ob, obese; PT, physical training; SBP, systolic blood pressure; TC, total cholesterol; TG:HDL, ratio of triglycerides to high-density lipoprotein cholesterol; TNF-α, tumor necrosis factor-α; VAT, visceral adipose tissue; VLDL, very-low-density lipoprotein cholesterol; VO_2, volume of oxygen; $VO_{2\,max}$, maximum volume of oxygen; $VO_{2\,peak}$, peak volume of oxygen; waist, waist circumference.

and cardiometabolic risk in obese individuals even without changes in body weight.

Improvements in body composition from aerobic training typically result from increased energy expenditure (calories burned). There is no clear effect of intensity of aerobic exercise training on body composition when energy expenditure is matched between groups. Kang et al[35] compared aerobic exercise intensities in obese adolescents (aged 13–16 years) on an 8-month exercise intervention program (moderate intensity at 55%–60% peak rate of oxygen consumption [$VO_{2\,peak}$] vs high intensity at 75% to 80% of VO_{2peak}) with matched energy expenditure between groups (250 kcal/session). Decreases in body fat in the high intensity exercise group (–2.85%) were not significantly different from the changes in body fat in the moderate intensity group (–1.42%). Although the study may have been underpowered to detect differences in percent body fat, the results of the study showed that modest improvements in body composition can be obtained by either moderate or high-intensity aerobic training, with no clear effect of exercise intensity when energy expenditure is the same between groups.

Although some small beneficial changes in body fat ensue following aerobic exercise in obese adolescents, Suh et al[33] also found reductions in muscle mass in the aerobic training group (–0.20 ± 0.80 kg) compared with the diet-only control group (0.65 ± 0.98 kg; $P < 0.05$) following an exercise intervention. The results should be interpreted with caution because bioelectrical impedance (a less robust measure of body composition) was used to assess changes in total body fat and total muscle mass. A more recent study by Lee et al[32] used DEXA and MRI to evaluate changes in muscle mass following exercise training in obese adolescents aged 12 to 18 years. The study showed no differences in either the aerobic or resistance exercise groups in total fat-free mass assessed by DEXA. Furthermore, the changes in skeletal muscle mass assessed by MRI from the aerobic training group were not significantly different from the changes in the non-exercising control group (1.0 ± 0.3 vs 0.5 ± 0.4 kg; $P = 0.155$). Only the resistance exercise group showed increases in skeletal muscle mass compared with the control group (1.4 ± 0.3 vs 0.5 ± 0.3 kg; $P = 0.01$). It is important to consider these findings when designing exercise programs for youth. Combining aerobic and resistance exercise training could be the optimal prescription to maximize the potential benefits of both modalities and counteract the potential decrease in muscle mass associated with weight loss following aerobic exercise training.

From the evidence presented cumulatively, aerobic exercise training interventions at moderate to vigorous intensity (55% to 80% $VO_{2\,peak}$) with more frequent exercise sessions (≥ 3 sessions/week) for longer durations (≥ 40 minutes/session) combined with multidisciplinary lifestyle and dietary education/dietary restriction programs show the largest improvements in overall body composition.[13–19,21–23,32]

Effects of Aerobic Exercise Training on Cardiorespiratory Fitness

The best available measure of cardiorespiratory fitness is the maximal rate of oxygen consumption ($VO_{2\,max}$) or the $VO_{2\,peak}$ rate, defined as the maximal amount of oxygen that exercising muscles can utilize during a maximal exercise test. Poor cardiorespiratory fitness has been identified as a stronger determinant of CVD risk and premature mortality[9] than total body weight or total body fat. Obese adolescents have lower cardiorespiratory fitness compared with their leaner peers[6,36] and have a higher risk of chronic disease(s). Although aerobic training interventions use different tests to assess cardiorespiratory fitness,[13,15,19,22,35] 4 studies in obese adolescents reported increases in $VO_{2\ peak}$ of 16.3% after 8 weeks of moderate intensity aerobic exercise training,[24] including +2.5 mLO_2/kg/min after 12 weeks of rope skipping,[6] +9.1 ± 0.9 mLO_2/kg/min after 3 months of moderate-intensity aerobic training,[32] +4.7 mLO_2/kg/min after 8 months of high-intensity aerobic training,[35] and +3.7 mLO_2/kg/min after 12 months of aerobic interval training.[19] Other studies did not report on cardiorespiratory fitness findings.[16–18,21]

When considering the effects of aerobic exercise training on cardiorespiratory fitness, it is important to consider the intensity of the exercise prescription and program compliance. One study[22] compared the effects of high-intensity aerobic exercise (75% to 80% VO_{2peak}) 5 days per week with a moderate-intensity aerobic group (55% to 60% VO_{2peak}) and a lifestyle-education–only group of obese adolescents, aged 13 to 16 years. After the 8-month intervention with matched energy expenditure (250 kcal/session calories expended during each exercise session were equal between groups), the high-intensity aerobic exercise group (n = 20) showed larger increases in cardiorespiratory fitness of 4.69 ± 1.02 mLO_2/kg/min compared with the lifestyle-education–only group (n = 18, decrease of 0.01 ± 0.45 mLO_2/kg/min; $P < 0.01$) but the high intensity aerobic exercise group increase was not significantly different from the increase seen in the moderate intensity aerobic exercise group (n = 21), which was +2.27 ± 0.94 mLO_2/kg/min). The observed improvements in both cardiorespiratory fitness and body composition were approximately twice as great in the high-intensity aerobic exercise group than in the moderate-intensity exercise group, but the study was likely underpowered to detect a difference between the groups. The study authors found that even though the mean average exercise training heart rate (HR) achieved in the high-intensity group (154 beats per minute [bpm]) was higher than that of the moderate-intensity group (138 bpm), it was difficult to maintain participants in the high-intensity target HR zone—the actual mean HR of 154 bpm achieved was lower than the prescribed average HR of 167 bpm. Furthermore, exercise compliance rates in both the moderate intensity (51%) and high intensity groups (54%) were low; the difference between the groups might have been more striking if adherence were higher. It may be difficult for previously inactive obese adolescents to perform high-intensity aerobic exercise for long periods of time; however, this study demonstrated that increases in cardiorespiratory fitness can be acquired by the use of moderate-intensity exercise prescription, which might reduce the level of physical strain participants may experience during exercise training and/or reduce the barriers associated with initiating and complying with an aerobic exercise program.

A study by Lee et al[32] demonstrated that high compliance (> 99%) with a moderate-intensity, 3-month aerobic exercise training program can result in marked improvements in cardiorespiratory fitness in obese adolescents aged 12 to 18 years. Participants in the study exercised (on a treadmill, elliptical ergometer, or stationary bike) 3 times weekly, starting at 40-minute sessions at 50% of VO_{2peak}, and progressing up to 60-minute sessions at 60% to 75% of $VO_{2\ peak}$. The aerobic exercise group increased VO_{2peak} by 9.1 ± 0.9 mLO_2/kg/min compared with a decline of –0.04 ± 1.1 in the control group ($P < 0.0001$).

Effects of Aerobic Exercise Training on Blood Pressure

Regular exercise is associated with a lower risk of developing hypertension in adults.[37] Although there are very limited studies that have specifically investigated the role of aerobic exercise alone on BP in obese adolescents, most studies found that aerobic exercise training was effective in lowering SBP[13,16,19,24,38] and DBP.[19,24,38]

Rocchini et al[38] investigated the effects on BP of a diet-plus-behavior-change group and exercise-plus-diet-plus-behavior-change group compared with a control group after a 20-week exercise intervention. The 60-minute exercise session was offered 3 days weekly at an intensity of 60% to 80% of maximal HR (HR_{max}). Both the diet-plus-behavior-change and exercise-plus-diet-plus-behavior-change groups had reductions in SBP and DBP compared with the control group ($P < 0.05$). Furthermore, the change in SBP in the exercise-plus-diet-plus-behavior-change group (129 ± 9 to 113 ± 6 mm Hg; $P < 0.05$) was significantly greater than that of the diet-plus-behavior–change group (127 ± 14 to 117 ± 8 mm Hg; $P < 0.05$). Kang et al[35] randomized obese adolescents, aged 13 to 16 years, to either lifestyle-education alone (n = 18), lifestyle-education-plus-moderate-intensity aerobic exercise (n = 21; 55% to 60% of $VO_{2\ peak}$), or lifestyle-education-plus-high-intensity aerobic exercise (n = 20; 75% to 80% of $VO_{2\ peak}$) for 8 months. The changes in SBP were not significantly different among the 3 groups, however, the improvements in DBP were significantly different only between the lifestyle-education group (increase of 1.00 ± 1.84 mm Hg) and the lifestyle-education-high-intensity aerobic exercise group (decrease of 5.92 ± 1.79 mm Hg; $P = 0.031$).[35] Similarly, another study investigated the effects of a multidisciplinary-approach group (combined dietary, exercise, and psychological advice [2 sessions] over the course of 12 months) compared with an aerobic-interval training group (4 x 4-minute intervals at 90% of HR_{max}, each interval separated by 3 minutes at 70% of HR_{max}, twice weekly for 3 months).[19] Participant SBP and DBP decreased significantly by 9.4 mm Hg and 5.5 mm Hg, respectively, per group, after 3 months of either multidisciplinary or aerobic-interval training.[19] In the multidisciplinary group, there was a significant decrease in SBP only after 3 months (–2.5 mm Hg) ($P < 0.05$). At 9 months post-intervention, however, mean arterial pressure remained 6.2 mm Hg lower than baseline for subjects in the aerobic-interval group. Similarly, Ben Ounis et al[24] found a significant decrease in SBP and DBP rates (–7.6% and –10.9%, respectively; $P < 0.01$) in an aerobic exercise training group (n = 16) compared with a control group (n = 16). It is important to note that the baseline average SBP for both groups was > 130 mm Hg.

Meyer et al[13] also showed that participants undergoing 6 months of aerobic exercise had decreased SBP (117 ± 7.1 mm Hg vs 113.1 ± 7.7 mm Hg; $P < 0.05$) compared with a non-exercising control group (121 ± 9.4 mm Hg vs 121.0 ± 8.6 mm Hg). Park et al[16] investigated the effect of a lifestyle-plus-aerobic exercise intervention on metabolic syndrome markers. They randomized 44 obese female adolescents, aged 13 to 15 years, to either a control group (n = 22) or a lifestyle-plus-aerobic exercise group (n = 22). The participants exercised 6 times weekly for 30 to 40 minutes per session at an intensity of 55% to 75% of age-matched HR_{max}. After 12 weeks, the lifestyle-plus-exercise group presented a significantly greater reduction in SBP compared with the control group (–6.5 ± 7.9 mm Hg vs –0.4 ± 4.7 mm Hg, respectively; $P = 0.005$), but neither a significant time nor significant group effect was found for DBP.

In summary, aerobic exercise training interventions of moderate to high intensity in obese adolescents showed reductions (in the range of –4 to –7 mm Hg) in both SBP and DBP, however, the effects on DBP were more modest.

Effects of Aerobic Exercise Training on Plasma Lipids

Some studies have investigated the combined effect of diet and aerobic exercise on plasma lipid levels, although the data reported has shown inconsistent results.[15–17,21,35] Some,[15–16,21] but not all[17,35] studies reported a significant decrease in total cholesterol, ranging from 9.7 to 22.3 mg/dL. Only 2 studies reported a significant decrease in LDL-C levels (–10.7 to –16.8 mg/dL).[15–16] No studies reported a significant increase in HDL-C levels,[17] or a decrease in triglyceride levels.[15,17] The studies make it difficult to elucidate the independent effect of aerobic exercise on plasma lipid levels in obese adolescents.

There are limited well-controlled studies that examine the effects of aerobic exercise alone on plasma lipid levels in obese adolescents.[6,13,23–24] Meyer et al[13] randomized 96 obese adolescents, aged 14.7 ± 2.2 years, to an aerobic exercise group or a non-exercising control group for 6 months. The exercise intervention group participated in swimming, aqua aerobics, sports games, and walking for 1-hour sessions 3 times weekly for 6 months. The aerobic exercise group showed a significant decrease only in triglyceride levels (from 1.41 ± 1.14 to 1.04 ± 0.48 mmol/L; $P < 0.001$) and LDL-C levels (from 2.71 ± 0.70 to 2.57 ± 0.66 mmol/L; $P = 0.025$).[13] Lee et al[6] showed that a 12-week rope-skipping program (40- to 50-minute sessions weekly at 40% to 80% of HR_{max} with an energy expenditure of 300 to 400 kcal/day) in 11 obese female adolescents reduced total cholesterol and triglyceride levels but did not increase HDL-C levels. Another study by Ben Ounis et al[23] randomized obese adolescents, aged 12 to 14 years, to 3 groups: dietary restriction, aerobic exercise at the point of maximum fat oxidation, or restricted diet combined with exercise on plasma lipids for 2 months. The aerobic exercise program consisted of 4 weekly 90-minute sessions of running, jumping, and playing with a ball at a HR corresponding to maximum fat oxidation. The dietary restriction was –500 kcal/day.[23] The dietary intervention on its own promoted fat loss and reduced total cholesterol and LDL-C levels, whereas the aerobic exercise training alone increased lipid oxidation during exercise, reduced plasma triglyceride levels, and increased HDL-C levels. Combined diet plus exercise training resulted in reductions in LDL-C levels and increases in HDL-C levels, HDL-C triglyceride ratio, and measures of maximal rate of lipid oxidation.[23] The results suggest that improvements in plasma lipid levels are more pronounced when aerobic training is combined with a dietary intervention.

Exercise training typically shows the largest improvements in obese adolescents with the most unfavorable plasma lipid profiles at baseline.[35] The limited data available indicate that a combination of a dietary intervention and aerobic exercise training maximize the decrease in plasma lipid levels in obese adolescents.

Effects of Aerobic Exercise Training on Inflammatory Markers

Obesity is associated with a low-level but chronic inflammatory state in adults and children.[39–42] High-sensitivity C-reactive protein (CRP) is one of the most sensitive indicators of inflammation,[43] and a higher concentration of CRP is also associated with greater body mass index (BMI), greater total body fat, higher BP and increased insulin resistance.[21,39,44] Most studies have shown that the obesity-related inflammatory state is reversible, at least in part by lifestyle interventions.[13,16,21]

Balagopal et al[21] investigated the effects of 3 months of moderate physical activity-plus-behavioral-plus-dietary-change lifestyle intervention (45 minutes of aerobic exercise training 3 times weekly, consisting mainly of brisk walking) on inflammatory and insulin-resistance markers in obese adolescents. The investigators found a significant reduction in circulating blood concentrations of CRP (mean decrease, ~ 30%, range; 20%–60%; $P = 0.02$) in the lifestyle intervention group (n = 8) compared with no changes in the obese adolescent control group (n = 7). The intervention group had a decrease in percent body fat (from 45.5 ± 2.3 to 39.2 ± 2.3%; $P < 0.01$) and an increase in fat-free mass (from 57.3 ± 3.8 to 63.6 ± 4.1 kg; $P < 0.01$). The decrease in percent body fat may in part explain the changes in blood CRP levels despite the fact that the intervention group maintained its weight (from 105.8 ± 5.2 to 104.5 ± 5.3 kg; $P = 0.15$). However, in view of the small sample size and the potentially confounding effects of dietary restriction and behavioral therapy on the outcomes, the independent contribution of aerobic exercise training should be interpreted with caution.

Another study assessed the effects of a 6-month aerobic exercise program (swimming, aqua aerobics, sports games, or walking for 1 hour sessions, 3 times/week) in 96 obese children and adolescents, aged 11 to 16 years, on flow-mediated vasodilation, carotid intima-media thickness, and cardiovascular risk factors.[13] The authors showed that a 6-month course of regular aerobic exercise restored endothelial function and decreased carotid intima-media thickness in the subjects by increasing flow-mediated dilation (intervention group increase of 127 ± 171% vs control group decrease of –7.3 ± 61.7%, $P < 0.001$).[13] The authors speculated that the increase in flow-mediated dilation might partly be due to a significant decrease in plasma CRP levels (from 4.84 ± 6.31 to 2.05 ± 2.44 mgl/L; $P = 0.013$) for the intervention group, which was not observed in the sedentary obese non-exercising control group (from 4.61 ± 0.54 to 3.36 ± 4.76 mgl/L; $P = 0.472$) although the authors did not evaluate the association between flow-mediated dilation and change in plasma CRP level. Similarly, Park et al[16] showed that a 12-week lifestyle-plus-aerobic-exercise intervention (30- to 40-minute sessions, 6 days weekly, at 55% to 75% of age-predicted HR_{max}) decreased circulating CRP in Korean obese adolescent girls. The intervention group (n = 22) had significantly greater reductions in CRP and percent body fat ($P < 0.001$) than the control group (change of –0.2 ± 0.9 mg/L and change of 0.3 ± 0.5 mg/L, respectively; $P = 0.041$). Another study[20] demonstrated that lower levels of fitness and greater levels of adiposity were associated with elevated circulating CRP level in black and white obese adolescents. Circulating CRP level was partially explained by percent body fat ($r^2 = 0.35$; $P \leq 0.0001$) and visceral fat ($r^2 = 0.06$; $P \leq 0.005$).[20] However, Barbeau et al[20] found that 8 months of moderate-to-high intensity aerobic exercise training (55% to 80% $VO_{2\,peak}$) did not influence circulating CRP level in obese adolescents.

C-reactive protein is produced in the liver and regulated by inflammatory cytokines, principally IL-6 and TNF-α. Two studies examined the effects of exercise training on circulating IL-6 and TNA-α concentrations.[18,21] Although both studies involved 3 weekly exercise sessions of 45 minutes each over 3 months, exercise intensities were not specified in either study and the types of aerobic exercise prescribed were very different. The aerobic exercise program used by Balagopal et al[21] incorporated brisk walking and resulted in a significant decrease in circulating IL-6 concentrations (25%; $P = 0.02$), whereas Rosenbaum et al[18] incorporated dance and kickboxing exercises with the same frequency of exercise sessions but did not observe significant changes in subject IL-6 or TNF-α concentrations after 3 to 4 months of aerobic exercise compared with the control group.[18] Percentage of body fat (–1.3%) and BMI (–0.7 kg/m^2) decreased in the exercise-intervention group compared with baseline ($P < 0.05$) but these changes did not differ from those in the control group. Although a decrease in percent body fat seems to be associated with reductions in plasma levels of inflammatory markers, the paucity of well-controlled studies and lack of exercise program details make it difficult to reach a conclusion on the effects of aerobic exercise on inflammatory markers.

Effects of Aerobic Exercise Training on Insulin Resistance Markers

The effect of aerobic exercise training on indices of insulin resistance in obese adolescents is not clear because study results have been inconsistent. Some studies that used a combination of diet and aerobic exercise found reductions in insulin resistance,[16–17,21] while others did not.[18,35] One study recruited obese adolescents from different ethnic backgrounds[35] and fasting insulin and glucose levels were measured for control, moderate- and high-intensity aerobic exercise groups (see Effects of Aerobic Exercise Training on Cardiorespiratory Fitness for study details). Study data revealed a significant ethnicity effect, such that the black adolescents had greater changes in insulin levels than the white adolescents (32.07 vs –25.86 pmol/L, respectively; $P = 0.032$).

Moreover, another study investigated the effect of a school-based intervention (in-class educational presentations on health, nutrition, and exercise plus an aerobic exercise program) on T2DM risk factors.[18] After the intervention, the quantitative insulin sensitivity check index (QUICKI) was significantly higher in the intervention group compared with the control group (0.35 ± 0.01 and 0.33 ± 0.01, respectively; $P < 0.05$), suggesting decreased insulin resistance. The QUICKI value was no longer significantly different between groups when corrected for body fat, suggesting that insulin sensitivity changes reflected fat changes. No significant change was observed in fasting blood glucose insulin levels and insulin concentration, nor in acute insulin response.[18]

Conversely, another study investigated the effect of dietary-restriction only, exercise-only or diet-plus-exercise on insulin resistance.[23] After a 2-month intervention, there were significant reductions in fasting blood glucose insulin levels in the exercise-only and combined diet-plus-exercise groups: –5.1 ± 1.3 μU/mL ($P < 0.05$) and –9.4 ± 3.6 μU/mL ($P < 0.01$), respectively. The homeostatic model assessment–insulin resistance (HOMA-IR)[45] was significantly improved in the exercise-only ($P < 0.05$) and combined diet-plus-exercise ($P < 0.01$) groups after the intervention, whereas the diet-only group showed no significant decrease in HOMA-IR values. The results suggest that exercise reduces HOMA-IR and fasting blood glucose insulin levels and the combination of diet plus exercise results in further reductions. Another study investigated the 3-month effect of aerobic exercise alone and resistance exercise alone without caloric restriction compared with a non-exercising control group on insulin sensitivity in obese adolescent boys.[32] After the 3-month intervention, insulin sensitivity increased in the resistance training group only and not in the aerobic training group (0.8 ± 0.2 mL/kg/min per μU/mL; $P = 0.009$; and 0.4 ± 0.2 mL/kg/min per μU/mL; $P = 0.125$, respectively). No changes were observed in insulin secretion with the hyperglycemic clamp, disposition index, or in the oral glucose tolerance tests. Change in insulin sensitivity was significantly related to changes in visceral adipose tissue in kilograms ($r = -0.47$; $P = 0.003$).[32]

Most studies that investigated the effect of aerobic exercise without caloric restriction on insulin sensitivity found favorable changes (decreases of –1.0 to –2.0 in HOMA-IR).[6,16–17,19,21] After a 3-month, moderate-intensity exercise intervention, Balopagal et al[21] showed a significant decrease (~24%; $P < 0.01$) in HOMA-IR values. Similarly, another study reported a significant decrease of 1.0 ± 1.2 in HOMA-IR values ($P = 0.017$) after a lifestyle behavior–based intervention combined with exercise for 12 weeks compared with a control group.[16] A significant decrease in fasting blood glucose and insulin levels were reported (–8.8 ± 6.6 mg/dL; $P = 0.002$ and –3.4 ± 4.8 μU/mL; $P = 0.016$, respectively) without changes in levels of glycated hemoglobin (HbA_{1c}).[16] In addition, after a 12-month intervention of lifestyle and behavior modification combined with exercise twice per week for 50 minutes per session, changes in HOMA-IR values between intervention and control groups at 6 months (–1.51 and +0.33, respectively) and 12 months (–1.52 and +0.99, respectively) were significantly different ($P < 0.001$).[17] There was no significant difference in fasting blood glucose after the intervention.[17]

Lee et al[6] found similar results after a 12-week intervention in obese adolescents aged 16.7 ± 0.7 years. The participants in the exercise group had decreased fasting plasma insulin (19.36 ± 6.23 to 12.75 ± 3.42 μIU/mL; $P = 0.009$) and decreased insulin resistance (HOMA-IR values: 6.79 ± 2.01 to 4.79 ± 1.30; $P = 0.002$) compared with the control group (insulin: 13.14 ± 6.24 to 17.00 ± 4.10 μIU/mL and HOMA-IR values: 4.02 ± 1.83 to 6.39 ± 1.53). One study[19] compared the effect of a multidisciplinary lifestyle education approach with an aerobic interval training program (4 x 4 -min intervals at 90% of HR_{max}) on cardiovascular risk factors in overweight adolescents. After a 3-month intervention, the homeostasis model assessment index for insulin sensitivity in percent (HOMA2-%S, an updated computer model of HOMA-IR where 100% is considered normal)[46] increased by 23.9% and 10.7% in the exercise and multidisciplinary groups, respectively.[19] At the 12-month follow-up, insulin sensitivity measured by HOMA2-%S was still higher than baseline levels by 17.6% and 14.9% in the exercise and multidisciplinary groups, respectively.[19] Taken together, these studies suggest that aerobic exercise training decreases insulin resistance independently of diet.

Summary

To date, a limited number of randomized controlled studies have examined the effects of aerobic exercise training on body composition, lipid levels, indices of insulin resistance and inflammatory markers in obese adolescents. The studies have shown that aerobic exercise caused small to moderate decreases in overall body weight, percent body fat, waist circumference, visceral fat, and BP in obese adolescents, aged 13 to 18 years. The effects of aerobic exercise training on markers of insulin sensitivity (ie, fasting blood plasma glucose, HOMA-IR values), plasma lipid levels, and inflammatory markers (CRP, IL-6, TNF-α) remain inconclusive due to the paucity of studies and further study is warranted. Table 2 summarizes the effects of aerobic exercise training on the physical and biochemical variables of obese adolescents reviewed in our article.

The Canadian Physical Activity Guidelines published by the Canadian Society for Exercise Physiology[47] state that adolescents (aged 12–17 years) should engage in ≥ 60 minutes of moderate to vigorous intensity physical activity every day. Furthermore, these recommendations state that adolescents should engage in vigorous intensity physical activity and activities that strengthen muscle and bone ≥ 3 days per week. The cumulative evidence from our review supports these aerobic exercise training recommendations and highlights the notion that greater participation and compliance to physical activity programs can result in greater reductions in cardiometabolic risk factors and promote increased health benefits.

We have previously reviewed the effects of resistance exercise training and the combination of aerobic and resistance training on the cardiometabolic profile in obese adolescents.[48] Although our prior reviews of the literature[48,49]

Table 2. Summary of the Effects of Aerobic Exercise Training in Obese Adolescents[a]

Variable	Studies That Showed Significant Decreases	Studies That Showed Significant Increases	Studies That Showed No Significant Changes
Body composition			
Body weight	6, 14–17, 24, 32, 38		18, 19, 21, 23, 33
BMI	6, 13–18, 24, 33		19, 23, 32
Waist circumference	6, 14, 16, 19, 24, 32		23, 33
% BF	6, 14–19, 21, 22, 32, 38		13, 33
Visceral fat	22, 32		33
Cardiorespiratory fitness			
$VO_{2\,peak}$		6, 19, 22, 24, 32	
Blood pressure			
SBP	13, 16, 19, 24, 38		14, 17, 35
DBP	19, 24, 35, 38		14, 16, 17
Plasma lipid levels			
HDL-C		23, 24	6, 13, 14, 15, 16, 17, 18, 19,35
LDL-C	13, 15, 16, 23		14, 17, 18, 35
TC	6, 15, 16, 17, 23		14, 18, 35
LDL:HDL	21, 23		13
TC:HDL	16, 23	35	
TGs	6, 13, 14, 23, 24		15, 17, 18, 19
Inflammatory markers			
CRP	13, 16, 18, 21		14, 20
IL-6	18, 21		14
TNF-α			14, 18
Insulin resistance markers			
Fasting plasma glucose	16, 23, 24	6	17, 18, 32, 35
Fasting insulin	6, 13, 14, 16, 17, 19, 23,		18, 32, 35
HOMA-IR	6, 13, 14, 16, 17, 21, 23		
QUICKI	18		
(HbA_{1c})			13,16. 19
Insulin sensitivity		19	32

[a] Each number listed in columns corresponds with the reference number in the references section. Details on the methods of each of the studies can be found in Table 1.

Abbreviations: % BF, percentage of body fat; BMI, body mass index; CRP, C-reactive protein; DBP, diastolic blood pressure; HbA_{1c}, glycated hemoglobin; HDL-C, high-density liproprotein C; HOMA-IR, homeostatic model assessment–insulin resistance; IL-6, interleukin 6; LDL-C, low-density lipoprotein cholesterol; QUICKI, quantitative insulin sensitivity check index; SBP, systolic blood pressure; TC, total cholesterol; TGs, triglycerides; TNF-α, tumor necrosis factor-α; VO_{peak}, peak rate of oxygen consumption.

and meta-analyses[50–52] have examined the effects of different types of exercise interventions on risk factors and health benefits in obese youth, future randomized controlled trials are needed to quantitatively evaluate and synthesize the literature on the independent effects of each exercise modality (aerobic vs resistance vs combined), separating the effects of age (child vs adolescent), maturity (prepubertal vs postpubertal), sex, and ethnicity. Future meta-analytic reviews should also consider analyzing results separately for non-randomized, non-controlled trials compared with well-controlled interventions in obese youth.

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Conflict of Interest Statement

A. S. Alberga, MSc, A. Frappier, BSc, R. J. Sigal, MD, MPH, D. Prud'homme, MSc, MD, and G. P. Kenny, PhD, disclose no conflicts of interest.

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MANUSCRIPT 3: A Review of Resistance Exercise Training in Obese Adolescents

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Statement of contributions of collaborators:

A.S. Alberga conceived the topic and content of this review article, carried out the bibliographic search, article screening, evaluated the evidence and drafted and edited the manuscript. R.J. Sigal and G.P. Kenny provided analytical input and helped draft and edit the manuscript.

CLINICAL FOCUS: DIABETES AND OBESITY

A Review of Resistance Exercise Training in Obese Adolescents

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Abstract: Resistance training—also known as strength or weight training—has been well recognized by several national organizations as a safe and beneficial exercise modality for the health and well-being of children and adolescents. Resistance exercise improves muscular strength and can improve body composition (eg, increase lean body mass and decrease percent body fat) provided that a sufficient exercise stimulus is prescribed. Effects of resistance exercise training on body composition and metabolic profile are well established in obese adults, but warrant further investigation in obese youth. This article reviews the rationale for including a resistance training component with interventions geared toward overweight and obese adolescents by discussing the effects on various health measures. Shortcomings in published trials, including small, ethnic minority samples of short-duration and low-frequency exercise sessions primarily conducted in prepubertal youth (rather than postpubertal adolescents) limit the generalizability of the published literature on the effectiveness of resistance exercise in obese adolescents.

Keywords: resistance training; exercise; obesity; adolescents; youth

Introduction

The prevalence of childhood obesity has increased dramatically in the past several decades.[1] Type 2 diabetes has reached pandemic proportions in youth.[2] Obese children are already presenting signs of adverse metabolic consequences, such as glucose intolerance, hyperinsulinemia, dyslipidemia, hypertension, and metabolic syndrome, which are all associated with excess adiposity.[3–5]

When considering that childhood body mass index (BMI),[6] adiposity,[7] physical activity habits, and fitness[8] strongly extend into adulthood, and obesity is associated with an increased morbidity and premature mortality,[9] prevention of chronic disease should begin early in life. Early identification and treatment of cardiometabolic risk in childhood and adolescence could help decrease the likelihood of developing diabetes and cardiovascular disease in adulthood.

Exercise can reduce the risk of diabetes[10–12]; however, it is unclear which types of exercise are best for reducing metabolic risk in youth, or which are most sustainable. In recent years, researchers have begun examining the effects of resistance exercise training in obese youth.[13–17] Resistance exercise training is a term used synonymously with strength training or weight training, which involves the use of muscular strength to work against a resistive force or move a weight.[18] Examples of resistance exercise are lifting free weights, using weight training machines and elastic resistance bands, and using one's own body weight as resistance (eg, push-ups and sit-ups). The weightbearing nature of aerobic exercise makes exercise adherence difficult for obese children,[3,19–21] but resistance exercise may be experienced differently in obese youth.

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It has been shown that obesity poses adverse consequences on the musculoskeletal system, such as altered gait patterns, as seen in obese prepubertal children,[22] and this may impact their exercise tolerance. However, some studies have shown that resistance training improves perceived self-confidence in obese youth,[23] which may in turn increase their participation in different types of physical activity in the long term.[24] The benefits of resistance exercise in reducing cardiometabolic risk are well documented in adults,[25] showing improvements in overall health,[26] increased muscle mass,[27] muscular strength,[28] insulin sensitivity,[29,30] bone mineral density,[31] and decreased abdominal adipose tissue.[28] In fact, several national organizations recognize resistance exercise training as safe and beneficial for the health and well-being of children and adolescents.[24,32]

The adolescent years are recognized as a critical period for the onset of obesity[33] and are of particular importance given that 80% of obese adolescents become obese adults.[13] However, strong evidence with large samples and well-controlled designs are lacking in exercise interventions, particularly in resistance training programs with obese adolescents. This article discusses the effects of resistance exercise on traditional risk factors for cardiovascular disease (CVD) in obese youth. It focuses on controlled studies incorporating a resistance training-only group in adolescents with obesity. Although most reviews have focused on the effects of resistance training alone, this article includes some studies that combined resistance with aerobic exercise in their interventions. For the purposes of this article, the term "youth" refers to children and adolescents aged ≤ 18 years; the terms "children" or "prepubescent youth" refer to those aged ≤ 12 years; and the terms "adolescents" or "postpubescent youth" are used to refer to those aged between 13 and 18 years.

Systematic review articles[34,35] and 2 meta-analyses[36,37] have established the benefits of resistance exercise training in obese youth. However, most of these articles have focused on the effects of resistance exercise training in overweight and obese prepubertal children and have not included more recent studies conducted in samples of overweight and obese postpubescent adolescents. A recent meta-analysis that included 42 studies from 1949 to 2009 with a total of 1728 participants (training group, 992; control group, 736) showed that physiological maturity is an important predictor of the resistance exercise training outcomes.[38] To our knowledge, only 5 randomized controlled trials incorporating a resistance exercise training component have been published thus far in obese adolescents aged 13 to 18 years.[14–17,39] Precise exercise program details on recent studies that have incorporated a resistance training component with obese adolescents aged 13 to 18 years can be found in Tables 1 and 2.

Effects on Musculoskeletal Fitness

Musculoskeletal fitness is defined as the ability of the muscular and skeletal systems to work together to perform work without undue fatigue.[40] Measurement of muscular strength, muscular endurance, and joint flexibility allows for a comprehensive assessment of musculoskeletal fitness. Muscular strength is the maximal force that can be produced by a muscle group, and muscular endurance is the ability of the muscle group to maintain force for longer periods.[40] Adult studies have shown that poor musculoskeletal fitness, particularly lower scores on the abdominal muscular endurance sit-up test, is linked to lower health status[41,42] and an increased risk of mortality.[43] Furthermore, low grip strength in particular has been shown to be a strong predictor of higher mortality in men.[43]

A substantial body of evidence supports the beneficial effects of resistance exercise on increasing muscular strength in obese adolescents,[14–17,44,45] with concomitant increases in lean body mass in some studies,[16,45] though others did not show increases in muscle mass.[14,15,17,44] These conflicting findings on changes in lean body mass may be due to short study duration (≤ 8 weeks),[17,44] less-than-optimal frequency of exercise sessions (≤ 3 sessions/week),[14,15,17,44] and/or less robust body composition assessment technique (bioelectrical impedance rather than dual-energy x-ray absorptiometry [DXA] or magnetic resonance imaging [MRI]).[44] The duration of intervention plays an important role in determining changes in muscular strength and body composition. Despite the large increase in strength typically observed within the first 2 to 8 weeks of resistance training, there is a weak association between the increase in muscular strength and the increase in muscle hypertrophy and increases in muscle mass.[46] Neural factors, such as recruitment, activation, and firing rate of motor units (motor neurons and their associated muscle fibers),[47] contribute to improvements in strength in the early stages of training. Prolonged periods of resistance training (> 10 weeks) are required for the size of the muscle fibers (ie, muscle hypertrophy) to increase and thus for increases in lean body mass to occur. These reasons may help explain the null findings in musculoskeletal fitness and body composition of several studies that employed a short intervention period (< 10 weeks) with obese youth.[17,48]

Despite the beneficial effects of resistance exercise observed in some of these studies, their results should

Table 1. Randomized Controlled Trials Including a Resistance Exercise Training Component with Obese Adolescents

Source	Sample	Groups	Frequency and Duration	Exercise Mode and Intervention	Equipment	Intensity	Main Outcomes on Body Composition and Metabolic Profile
Davis et al[15]	N = 54; Latino overweight and obese adolescents; aged 15.5 ± 1.0 years	1. Wait-list CG (n = 16) 2. Nutrition (n = 21) 3. Nutrition + ST (n = 17)	Nutrition + ST: 2 sessions/wk for 16 wks	**Nutrition group:** 1 session/wk for a 90-min culturally tailored dietary intervention **Nutrition + ST group:** 1 session/wk for a 90-min culturally tailored dietary intervention + supervised ST 60 min/session on 2 nonconsecutive days/wk. *Session 1*: 5-min warm-up and cool-down, stretches, abdominal exercises, 2 compound lower body and 3 upper body exercises. *Session 2*: 5-min warm-up and cool-down, stretches, abdominal exercises, 2 compound upper body and 3 isolated lower body exercises.	Machines, free weights	**Nutrition + ST group:** Wks 1–4: higher volume 1 set, 10–15 reps. Wks 5–10: 2 sets, 13–15 reps. Wks 11–16: 3 sets, 8–12 reps. 1–2 min rest between sets/exercises.	No significant intervention effects on insulin sensitivity, body composition, and most glucose/insulin indices. Glucose incremental area under the curve decreased by 18% in the nutrition group and by 6.3% in the nutrition + ST group compared with a 32% increase in the wait-list control group.
Davis et al[14]	N = 41; Latina overweight and obese females; aged 15.2 ± 1.1 years	1. Wait-list control (n = 7) 2. Nutrition (n = 10) 3. Nutrition + ST (n = 9) 4. CAST (n = 15)	Nutrition + ST: 2 sessions/wk, Nutrition + CAST: 2 sessions/wk 16 wks	**Nutrition group:** 1 session/wk for a 90-min culturally tailored dietary intervention **Nutrition + ST group:** 1 session/wk for a 90-min culturally tailored dietary intervention + supervised ST 60 min/session on 2 nonconsecutive days/wk. *Session 1*: 5-min warm-up and cool-down, stretches, abdominal exercises, 2 compound lower body and 3 isolated upper body exercises. *Session 2*: 5-min warm-up and cool-down, stretches, abdominal exercises, 2 compound upper body and 3 isolated lower body exercises.	Machines, free weights	**Nutrition + ST group:** Wks 1–4: higher volume 1 set, 10–15 reps. Wks 5–10: 2 sets, 13–15 reps. Wks 11–16: 3 sets, 8–12 reps. 1–2 min rest between exercises. **Nutrition + CAST:** Personalized, progressive increase throughout the intervention depending on fitness and strength improvement.	Significant overall intervention effects for all adiposity measures (weight, BMI, BMI z-scores, and total body fat) with a 3% decrease in the nutrition + CAST group compared with a 3% increase in the nutrition + ST group ($P \le 0.05$). Fasting glucose increased by 3% in the nutrition group while the nutrition + CAST group decreased by 4% ($P \le 0.05$).

(*Continued*)

Table 1. (*Continued*)

Source	Sample	Groups	Frequency and Duration	Exercise Mode and Intervention	Equipment	Intensity	Main Outcomes on Body Composition and Metabolic Profile
				Nutrition + CAST group: 2 supervised sessions/wk of 60 min on nonconsecutive days. Each session was composed of 30 min of aerobic activity (treadmill, elliptical, aerobic classes) coupled with 30 min of ST. Participants completed 2 different ST exercises every minute (upper and lower body exercise were combined) without stopping followed by 2-min aerobic exercises.			
Shaibi et al[16]	N = 22; Latino males; aged 15.1 ± 0.5 years	1. Wait-list CG (n = 11 males) 2. Progressive RT (n = 11 males)	RT: 2 sessions/wk, 16 wks	**RT group:** *Session 1:* 5-min warm-up and cool-down, stretches, abdominal exercises, 2 compound lower body and 3 isolated upper body exercises. *Session 2:* 5-min warm-up and cool-down, stretches, abdominal exercises, 2 compound upper body and 3 isolated lower body exercises.	Machines, free weights	Wks 1–4: higher volume 1 set, 10–15 reps. Wks 5–10: 2 sets, 13–15 reps. Wks 11–16: 3 sets, 8–12 reps. 1–2 min rest between sets/exercises.	Significant increases in insulin sensitivity in the RT group compared with the CG ($P < 0.05$) even after adjustment for changes in total fat mass and total lean mass ($P < 0.05$). Compared with baseline, the RT group also increased insulin sensitivity by 45.1% ± 7.3% vs –0.9% ±12.9% in the CG.
Lau et al[17]	N = 36; Chinese obese youth (12 girls, 24 boys); aged 10–17 years	1. Hypocaloric diet (11 males, 5 females) 2. RT + hypocaloric diet (14 males, 7 females)	RT: 3 sessions/wk, 6 wks	**RT group:** Circuit-based (warm-up, cool-down, 10 RT exercise stations) and hypocaloric diet.	Machines, stacked weights	70%–85% 1-RM, ≥ 5 lifts in full range of motion 60-min 3-set circuit, 3–5 min rest between sets.	No significant group or interaction effects were found on any body composition or metabolic variable following the intervention. No differences in psychological well-being (anxiety and depression) were reported between groups.

(*Continued*)

Table 1 (*Continued*)

Source	Sample	Groups	Frequency and Duration	Exercise Mode and Intervention	Equipment	Intensity	Main Outcomes on Body Composition and Metabolic Profile
Wong et al[39]	N = 24; obese males; aged 13–14 years	1. EG (n = 12) 3. CG (n = 12)	EG: 2 sessions/wk, 12 wks	**EG group:** 7- to 10-min warm-up/cool-down and stretching. EG exercises. Each session lasted 45–62 min. 20–35 min of circuit-based light RT with 4–7 resistance stations using body weight and progressed to using medicine balls (2–5 kg) alternating with 3–5 AT stations. Each AT station lasted 5–10 min. Each RT station duration increased from 1–3 min.	Alternating between indoor and outdoor activities. **AT:** Games, sports, stair-climbing, cycle ergometer, treadmill walking. **RT:** Using body weight as resistance, medicine balls.	**AT:** Start at 50%–60% of HR$_{max}$ gradually progressed to 85% HR$_{max}$. **RT:** Exercise circuits gradually increased from 1–3 sets, 8–25 reps.	Significant decreases in BMI, systolic blood pressure, and submaximal HRs following EG. EG also showed an increase in lean body mass following training. After controlling for baseline weight, height, and BMI, EG had a lower percent body fat compared with the CG at 12 wks ($P < 0.05$).

Abbreviations: AT, aerobic training; BMI, body mass index; CAST, nutrition and combination of AT and ST; CG, control group; EG, circuit-based RT + AT exercise group; HR, heat rate; HR$_{max}$, maximum heart rate; 1-RM, 1-repetition maximum; RT, resistance training; ST, strength training.

be interpreted with caution. Some of these trials were nonrandomized and/or did not include a nonexercising control group,[45] or their sample was composed of both prepubertal and postpubertal youth,[44] for whom some changes may be dependent on pubertal maturation. Moreover, most of these studies assessed musculoskeletal fitness using the 1 repetition maximum test only[14–17] but did not assess whole-body musculoskeletal strength, muscular endurance, and joint flexibility. One study conducted by Yu et al[23] in 82 overweight and obese prepubertal children aged 8 to 11 years showed significant improvements in hand-grip (upper body muscular strength), shuttle-run (cardiorespiratory fitness), sit-up (abdominal muscular endurance), and push-up (muscular endurance) scores in both the diet-alone control group and the diet-plus-resistance group, although greater improvements were seen with the addition of the strength training exercise. Future studies should examine the effects of resistance exercise on a more comprehensive assessment of whole-body musculoskeletal fitness, including testing for muscular strength, muscular endurance, muscular power, and flexibility, since physical fitness is associated with better quality of life.[49]

It has been proposed that increases in muscular strength in children are due to enhanced neuromuscular function (ie, increased firing rate and increased motor unit recruitment) rather than increases in muscle size (ie, hypertrophy).[50] In postpubescent adolescents, muscular adaptations to resistance training may be explained by increases in lean body mass due to muscle hypertrophy and improvements in muscle quality.[45] The meta-analysis by Behringer et al,[38] which summarized the effects of resistance training in different age groups and maturity levels by using the results of randomized and nonrandomized controlled trials in healthy children and adolescents aged < 18 years, reported that trainability of muscular strength increases with age. The authors also showed that longer-term interventions and greater number of resistance training sessions per week are associated with higher strength gains.

Effects on Total Body Fat and Abdominal Adiposity

Individuals with central obesity (ie, more body fat distribution in the trunk and abdomen) have increased risks of diabetes, CVD, and mortality compared with individuals

Table 2. Nonrandomized, Noncontrolled Trials Including a Resistance Exercise Training Component with Obese Adolescents

Study	Sample	Groups	Frequency and Duration of Intervention	Exercise Mode and Intervention	Equipment	Intensity	Main Outcomes on Body Composition and Metabolic Profile
Van Der Heijden et al[45]	N = 12; obese adolescents; aged15.5 ± 0.5 years	1. RT (n = 12)	2 sessions/wk; 12 wks	1-hour training session, exercising all major muscle groups. The 1-hour session included: 10-min warm-up, 40-min RT, and 10-min cool-down. There was ≥ 1 day of rest between sessions.	Body weight as resistance, hand-held weights, cables, weight-stack machines	Wks 1 and 2, resistance ~50% of 3-RM, with 2–3 sets of 8–12 reps. The weights and repetitions are then increased gradually according to each individual's ability, reaching ~80%–85% of 3-RM max with 3 × 15–20 reps during wks 9–12. During the exercise program, first the number of reps and subsequently resistance (weight) were increased.	Peak torque, as a surrogate measure of muscle quality, increased for both legs. Upper and lower body strength increased. Body weight increased from 97.0 ± 3.8 kg to 99.6 ± 4.2 kg ($P < 0.01$). The major part (~80%) was accounted for by increased lean body mass (55.7 ± 2.8 kg to 57.9 ± 3.0 kg; $P \leq 0.01$). Total, visceral, hepatic, and intramyocellular fat content did not change. Hepatic insulin sensitivity increased by 24% ± 9% ($P < 0.05$), while peripheral insulin sensitivity did not change significantly.
Naylor et al[57]	N = 23; obese adolescents; RT: aged 12.2 ± 0.4 years; CG: aged 13.6 ± 0.7 years	Participants selected either: 1. Supervised group RT program (n = 13) 2. Nonexercise CG (n = 10)	3 sessions/wk; 8 wks	1-hour training sessions: 10-min warm-up, 10-min cool-down. The RT program concentrated on the large muscle groups. After a 10-min warm-up period of stretching and low-intensity cycle or treadmill exercise, each RT session began with 1 min of 8 reps of an RT exercise on a machine. Participants had 1 min of rest and stretching between weight machines. This circuit continued until all 10 machine stations were completed. Participants completed 2 sets of the weight circuit at each visit.	Weight-stack machines	This exercise was initially set at an intensity of ~75% maximum voluntary contractile strength, which was progressively increased to ~90%.	RT group increased lean body mass (41.2 ± 3.7 kg vs 42.1 ± 3.0 kg; $P < 0.05$) and decreased percent body fat (49.6% ± 1.4% vs 48.5% ± 1.5%; $P < 0.01$) from baseline to post-intervention. Sum of bench press and dual leg press maximal strengths significantly increased (77 ± 4 kg to 117 ± 9 kg; $P < 0.0001$). RT was associated with a modest, although significant, decrease in SBP (120 ± 2 mm Hg vs 116 ± 3 mm Hg; $P < 0.05$), whereas there was no difference in the CG (122 ± 2 mm Hg vs 122 ± 2 mm Hg).

(*Continued*)

Table 2. (*Continued*)

Study	Sample	Groups	Frequency and Duration of Intervention	Exercise Mode and Intervention	Equipment	Intensity	Main Outcomes on Body Composition and Metabolic Profile
Bell et al[48]	N = 14; obese youth; aged12.7 ± 2.32 years	1. Circuit-based mixed aerobic and resistance exercise program	3 sessions/wk; 8 wks	1-hour supervised session included 10-min warm-up, 40-min circuit-based mixed aerobic and resistance stations, and 10-min cool-down. 10-min warm-up period of stretching and low-intensity aerobic exercise on a cycle ergometer or treadmill. Participants began with 1 min of aerobic exercise then 1 min at an resistance exercise station until all 10 stations were completed. Subjects completed 2 sets of this circuit at each of the 3 weekly visits to the gymnasium for 8 wks.	Cycle ergometer, treadmill, weight-stack machines	Each exercise session began with 1 min of cycle ergometry (initially maintained at 65% of maximum heart rate, progressed to 85% by wk 3) followed, at the sound of a buzzer, by movement to the first weight stack machine (12 reps/min, initially maintained at ~55% of pretraining maximum voluntary contraction, progressed to ~65% by wk 3).	Insulin sensitivity improved significantly after 8 wk of training (MIbm 8.20 ± 3.44 to 10.03 ± 4.33 mg/kg/min; $P < 0.05$). Submaximal exercise HR responses were significantly lower postintervention ($P < 0.05$), indicating an improvement in cardiorespiratory fitness. There were no differences in lean body mass or abdominal fat mass.
Watts et al[56]	N = 19; obese adolescents; (9 males, 10 females) aged14.3 ± 1.5 years	1. Randomized cross-over study of circuit training combined aerobic and resistance exercise	3 sessions/wk; 8 wks	1-h sessions of circuit training exercise each wk involving both cycle ergometer and RT.	Cycle ergometer, RT equipment not specified	Cycle ergometry was maintained at 65%–85% of maximum HR and RT intensity at 55%–70% of pre-training maximum strength. (Resistance exercise was not described in detail.)	Circuit training decreased abdominal and trunk fat and significantly improved fitness and muscular strength ($P < 0.05$).

Abbreviations: AT, aerobic training; CG, control group; HR, heart rate; reps, repetitions; 1-RM, 1-repetition maximum; RT, resistance training; SBP, systolic blood pressure.

with lesser degrees of abdominal adiposity.[51,52] Abdominal adiposity is best measured using MRI or computed tomography (CT). These 2 methods can distinguish between visceral adiposity (ie, fat surrounding the organs) and subcutaneous fat (ie, fat beneath the skin). Visceral adiposity is a strong predictor of metabolic abnormalities, and increased levels of this fat depot are strongly related to metabolic syndrome, type 2 diabetes, and CVD.[52,53] The waist circumference measurement is a reasonable proxy of total adipose tissue; the correlation between waist circumference and total fat mass ranges from 0.85 to 0.93.[54]

Resistance Training Alone

Few randomized controlled trials have examined the effects of resistance exercise training alone on body composition in overweight and obese adolescents,[14–17,39] and these trials have yielded inconclusive results. Some studies have shown decreases,[16] whereas others reported no difference[15,45] or increases[14] in percent body fat of obese adolescents following a resistance exercise training program. Shaibi et al[16] randomly assigned a small sample of male Latino adolescents (N = 22) into a wait-list control group (n = 11) or a strength training group (n = 11) that exercised 2 times per week for

16 weeks. Investigators found that percent body fat decreased significantly in the resistance exercise group (35.3% ± 2.4% to 32.8% ± 2.1%; $P < 0.05$) compared with baseline, without changes in fat mass. However, these changes were not found to be significantly different from the control group. Davis et al[15] randomly assigned a larger sample of overweight male and female Latino adolescents (N = 54) a wait-list control group (n = 16), a nutrition education-only group (n = 21), or a nutrition and strength training group (n = 17), and did not find any changes in body composition after 16 weeks of nutrition education in combination with strength training. Davis et al[14] subsequently conducted a pilot study that included the same groups used in their previous study plus 1 additional group: a nutrition plus combined aerobic and strength training group, in a sample of female Latina adolescents. They reported that only the combined aerobic and strength training group with the nutrition component decreased in total fat mass, whereas the strength training and nutrition group showed increases in total fat mass (–4.3% ± 4.2% vs 1.8% ± 9.9%; $P = 0.045$).

Despite the well-documented correlation between high abdominal adiposity and metabolic risk,[52] most randomized controlled trials did not publish results on waist circumference or other measures of abdominal fat distribution following resistance exercise training.[14–16,39] A nonrandomized study by Van Der Heijden et al[45] did not show differences in percent body fat (DXA) or visceral fat content (MRI), although there was a small increase in subcutaneous fat at postintervention (5% ± 2%; $P < 0.05$) in the small sample of obese adolescents (N = 12) aged 15.5 ± 0.5 years following the resistance exercise program. However, Benson et al[44] found that high-intensity, whole-body resistance exercise training showed promising results in a group of 78 youths aged 12.2 ± 1.3 years (51% of whom were overweight or obese) who trained twice per week for 8 weeks. The high-intensity progressive resistance training was at an intensity corresponding with a rating of perceived exertion (RPE) of 15 to 18 on the Borg scale,[55] which is comparable with 80% of maximal strength for 2 sets of 8 repetitions for 11 exercises using free weights and ankle weights.[44] In the resistance training group, waist circumference (–0.8 ± 2.2 cm vs 0.5 ± 1.7 cm; F = 7.59; $P = 0.008$) and percent body fat (–0.3% ± 1.8% vs 1.2% ± 2.1%; F = 9.04; $P = 0.004$) were significantly decreased when compared with the nonexercising control group at postintervention.

It is important to consider intensity when designing a resistance training intervention. Some studies with obese adolescents,[14–16,45] but not all,[17,39,48,56,57] included detailed weekly descriptions of resistance exercise intensity throughout the intervention, which is critical to evaluate if the training stimulus was sufficient to initiate changes in body composition and physical fitness. Intensity refers to the amount of resistance used for a specific resistance training exercise, whereas volume is the total amount of work performed in 1 training session.[24] The RPE[55] (range, 6–20) used by Benson et al[44] and a modified version used by Shaibi et al[16] is a subjective way of assessing exercise intensity to verify that the patient's perception of effort during the exercise is in accordance with the intensity that is prescribed for that particular patient. Over time, the resistance training program should progressively increase in intensity to include more sets of heavier loads on large muscle groups to optimize gains in strength and power.[24] Despite the mixed-age group of varying pubertal maturity levels and adiposity levels, Benson et al[44] applied this progressive intensity model to increase the number of sets and resistance while decreasing the number of repetitions to maximize strength/power. Perhaps the higher intensity of resistance exercise training used by Benson et al[44] would also be beneficial in an older sample of obese adolescents.

Combined Aerobic and Resistance Training

Treuth et al[58] observed the effects of a 5-month combined aerobic and resistance exercise training program on visceral adipose tissue in a small sample of obese prepubertal girls aged 7 to 10 years. The results showed no differences in visceral fat[58] or energy expenditure,[59] although increases in strength,[59] and subcutaneous and total body fat were observed after the training program.[58] In another study, Woo et al[60] randomly assigned a group of prepubertal youths aged 9 to 12 years to a dietary modification-only group (n = 41) or to a diet plus a supervised combined circuit program of aerobic and resistance exercise training group (n = 41) for 6 weeks and then subsequently for 1 year. The study showed that the continued training group (n = 22) had lower percent body fat compared with the detraining group (n = 19) and the diet-only group (n = 41) at 1-year follow-up. Although the evidence on the effect of resistance exercise training on prepubertal obese children is conflicting, changes in growth or insufficient energy expenditure may account for the lack of difference in percent body fat and visceral fat following exercise interventions in obese prepubertal children.[61]

In another study, Watts et al[56] conducted an 8-week randomized crossover study of combined aerobic and resistance circuit training in a sample of 19 obese adolescents aged 14.3 ± 1.5 years. The results showed significant decreases in trunk fat mass (19.0 ± 1.0 kg vs 18.3 ± 1.0 kg; $P < 0.05$) and abdominal fat mass (8.6 ± 0.6 kg vs 8.0 ± 0.4 kg; $P < 0.05$) as assessed by DXA following the circuit training regime. However, specific details on exercise prescription related to types of strength training exercises were not provided. Circuit training typically involves moving at a faster pace between exercise stations with minimal rest periods between sets, and therefore may induce changes in cardiorespiratory fitness, in contrast with conventional resistance exercise training, which involves longer rest periods between sets without increasing aerobic fitness. However, although some of the studies that employed a circuit training regime found significant improvements in body composition following resistance training,[14,16,39,56] others did not.[15,17,48]

A meta-analysis conducted by LeMura and Maziekas[36] showed that aerobic training plus high-repetition resistance exercise training produced a significantly larger reduction in percent body fat compared with either modality alone. In another review article, Maziekas et al[37] showed that the greatest treatment effects after 1-year follow-up were seen in programs that incorporated a resistance training component with obese youth. Limitations of these analyses include the fact that only 8 of the 30 studies incorporated a resistance training component, and most of the 8 studies examined prepubertal youths aged < 13 years. More recent systematic reviews[34,35] and a meta-analysis by Behringer et al[38] examined the effects of exercise training in children and adolescents, and reported a lack of methodologically robust studies assessing the effects of resistance training on body composition and metabolic health in youth.

Effects on Cardiorespiratory Fitness

Cardiorespiratory fitness, also known as aerobic fitness or aerobic capacity, is defined as the ability of the circulatory and respiratory systems to work together to supply adequate amounts of oxygen to supply the body with energy to sustain dynamic exercise. Cardiorespiratory fitness is a strong predictor of morbidity and mortality.[62] High cardiorespiratory fitness exerts protection against CVD and premature mortality in nonobese and obese adults.[62] The best measure of cardiorespiratory fitness is maximal oxygen consumption (VO_2 max) or peak oxygen consumption (peak VO_2), which is defined as the maximal amount of oxygen that exercising muscles can uptake during a maximal exercise test.

Resistance Training Alone

The effects of resistance exercise training on cardiorespiratory fitness in obese youth are not clear. To date, resistance training-only interventions in obese adolescents have not shown improvements in cardiorespiratory fitness[37] or do not report results on VO_2 max at postintervention.[14,15,17,39,56] We can infer from the randomized controlled studies that have been conducted in adults who are obese[63] and have type 2 diabetes[64,65] that inducing significant improvements in cardiorespiratory fitness may be achieved through consistent moderate-to-vigorous aerobic training and combined aerobic and resistance training together, not merely resistance exercise alone. However, these results have yet to be elucidated in a large sample of obese adolescents.

Combined Aerobic and Resistance Training

Very few studies[15,39,48,66] have investigated the effects of combined aerobic and resistance training in obese youth. However, none of these studies reported effects on VO_2 max from baseline to postintervention. Following a 12-week, twice-weekly circuit-based aerobic and resistance training program, Wong et al[39] observed decreases in resting heart rate and improvements in submaximal exercise heart rates, suggesting an improvement in cardiorespiratory fitness after training in obese male adolescents aged 13 to 14 years. These results are in agreement with nonrandomized controlled trials that also found decreases in resting heart rate[66] and submaximal heart rates[48,56] following the combined exercise intervention. To our knowledge, however, only 1 study employed a randomized controlled design. Davis et al[14] randomly assigned 41 overweight Latina adolescent females to 1 of 4 groups: control, nutrition-only, nutrition and strength training, or a nutrition and combined aerobic and strength training group for a 16-week intervention. Changes in cardiorespiratory fitness following the intervention were not reported. However, the authors reported results on habitual physical activity, as assessed by accelerometry and 3-day physical activity recalls, which may be associated with cardiorespiratory fitness in youth. The results from Davis et al[14] showed no significant across-group effects in total minutes of physical activity per day, percent time spent in different intensity levels per day, or total daily energy expenditure.

Effects on Insulin Sensitivity and Glucose

Resistance Training Alone

One research group has investigated the effects of resistance training on body composition and insulin sensitivity in overweight Latino adolescents.[14–16] Shaibi et al[16] randomly assigned overweight or obese male Latino adolescents (aged ~15 years) to a resistance training group or a wait-list control group for 16 weeks. Insulin sensitivity measured by the frequently sampled intravenous glucose tolerance test increased significantly in the resistance exercise training group (2.3 ± 0.3 to $3.2 \pm 0.3 \times 10^{-4}$ min^{-1} μU^{-1} mL^{-1}; $P < 0.05$), and the change was significantly different compared with baseline and the control group, even when accounting for changes in fat mass and lean mass. Intergroup comparisons showed that insulin sensitivity in the resistance training group increased by 45.1% ± 7.3% versus no change (0.9% ± 12.9%) in controls ($P < 0.01$). The researchers conducted a similar study to examine the effects of nutrition education in combination with resistance training but did not find comparable results.[15] Overweight Latino males and females (N = 54) aged 14 to 18 years were randomly assigned to 1 of 3 groups: a nonexercising control group, a nutrition education-only, or a nutrition education and strength training group for 16 weeks. This study did not observe any significant intervention effects on insulin sensitivity, body composition, or most insulin/glucose indices.[15] The exception was the glucose area under the curve, in which the nutrition education-only and the nutrition education and strength training group decreased by 18% and 6.3%, respectively, compared with a 32% increase in the control group. Despite significant decreases in waist circumference after 8 weeks in the high-intensity progressive resistance training group (mean change, −0.8 ± 2.2 cm vs 0.5 ± 1.7 cm in control; F = 7.59; $P = 0.008$), Benson et al[44] did not observe any metabolic changes in normal and overweight male and female adolescents aged 10 to 15 years compared with the nonexercising control group.

In an uncontrolled single-group study, Van Der Heijden et al[45] found that 12 weeks of resistance training twice per week in 12 obese Hispanic adolescents aged 15.5 ± 0.5 years induced a 24% ± 9% ($P < 0.05$) increase in hepatic insulin sensitivity (measured by the hepatic insulin sensitivity index = 1000/[glucose production rate × fasting insulin]) despite no changes in total body fat, visceral fat, hepatic fat, intramyocellular fat content, peripheral insulin sensitivity, fasting glucose, or fasting insulin. However, this study showed increases in muscle mass, muscular strength, and muscle quality, as assessed by measuring peak torque per gram of leg muscle before and after the intervention. To our knowledge, most of the studies conducted in obese adolescents did not report effects on glycated hemoglobin (HbA_{1c}),[14–18,44,45,48] except 1 randomized crossover study in 19 obese adolescents aged 14.3 ± 1.5 years by Watts et al,[56] which showed no changes in HbA_{1c}.

Combined Aerobic and Resistance Training

To our knowledge, just 1 pilot randomized controlled trial conducted in female adolescents only[14] evaluated the effects of strength training versus combined aerobic and strength training on insulin sensitivity. A small sample of overweight Latino adolescents (N = 41) aged 15.2 ± 1.1 years were randomly assigned to 1 of 4 groups: a nonexercising control group, a nutrition education-only group, a nutrition education with strength training group, or nutrition education and a combination of aerobic and strength training group, for 16 weeks. Only the combined aerobic and strength training group with the nutrition component demonstrated a decrease in total fat mass, whereas the strength training and nutrition group showed increases in total fat mass (−4.3% ± 4.2% vs 1.8% ± 9.9%; $P = 0.045$). Despite these beneficial changes in body composition, the study showed an intervention effect on fasting glucose, with a decrease in the combined aerobic and resistance training group and an increase in the nutrition-only group (−4.4% ± 6.6% vs 2.9% ± 5.9%; $P \leq 0.05$). No significant intervention effects for any other measure of glucose tolerance or insulin sensitivity were observed. The findings from a small study (N = 14) in obese youths aged 12.7 ± 2.32 years that incorporated a circuit-based program with mixed aerobic and resistance exercise training stations for three 1-hour sessions per week showed increases in insulin sensitivity after only 8 weeks of training.[48]

Benson et al[67] showed that muscular strength is an independent and powerful predictor of insulin sensitivity in a sample of 126 youths aged 10 to 15 years. Skeletal muscle is a significant site for glucose disposal, and several mechanisms have been proposed to explain the effects of resistance exercise on improvements in glycemic control, such as increasing concentration of glucose transporter type-4 (GLUT-4), increasing the sensitivity and the number of insulin receptors on the surface of the cell,[68] and increases in muscle mass.[69,70]

Effects on Blood Pressure

Resistance Training Only

Lau et al[17] randomly assigned 36 obese adolescents aged 10 to 17 years to a diet education and resistance training program or a diet education nonexercising control group for 6 weeks. Results at postintervention did not reveal any significant changes in systolic or diastolic blood pressure after the resistance exercise program. Limiting factors, such as short study duration, inclusion of prepubertal and postpubertal youths, and the absence of hypertensive measurements at baseline, may explain the null findings. Despite the nonrandomized design, one study[57] with 23 obese youth aged 12 to 13 years observed a modest decrease in systolic blood pressure (120 ± 2 mm Hg vs 116 ± 3 mm Hg; $P < 0.05$) in the resistance training group compared with no difference in controls (122 ± 2 mm Hg vs 122 ± 2 mm Hg). However, no changes were evident in diastolic blood pressure following the 8-week intervention (resistance group, 66 ± 2 mm Hg vs 68 ± 3 mm Hg; controls, 58 ± 2 mm Hg vs 59 ± 2 mm Hg).[57] Notwithstanding the other potential benefits of resistance exercise training on body composition and metabolic profile, most of the resistance exercise training studies recently conducted in overweight and obese adolescents did not report effects on blood pressure,[14–16,44,56] and thus remain inconclusive.

Effects on Lipid Profile

Resistance Training Only

One study examined the effects of a low-energy diet with or without resistance exercise training on serum lipids in 82 prepubertal children aged 8 to 11 years for 6 weeks.[71] Despite modest decreases in percent body fat from baseline to follow-up in the resistance training group (37.9% ± 4.1% to 37.3% ± 4.2%; $P < 0.05$), the mean change was not different from that of the control group (−0.7% ± 1.5% vs −0.2% ± 1.4% in control; $P > 0.05$). However, the increases in fat-free mass in the resistance training group were significantly different compared with the control group (mean change, 0.8 ± 1.1 kg vs 0.3 ± 1.2 kg; $P < 0.05$).

Low-density lipoprotein cholesterol decreased in the resistance training group, although these changes were not significantly different from the control group (mean change, −0.4 ± 0.5 mmol/L vs −0.2 ± 0.5 mmol/L in control; $P > 0.05$).[71] Total cholesterol also decreased from baseline to postintervention in both groups without any significant differences between the resistance training group and the control group, respectively (mean change, −0.3 ± 0.5 mmol/L vs −0.3 ± 0.5 mmol/L; $P > 0.05$).

Although resistance training may prevent the reduction in fat-free mass that is typically observed in diet-induced weight loss, the low-calorie diet restriction may be responsible for the improvement in lipid profile in both the control group and the resistance training group following the 6-week intervention. Some studies in overweight and obese adolescents did not observe any changes in lipids,[17,44,56] while most of the randomized controlled trials incorporating a resistance-only exercise group in overweight and obese adolescents did not report results regarding effects on lipid profile at postintervention.[14–16,72]

Combined Aerobic and Resistance Training

The studies that included a combined aerobic and resistance training component in a sample of overweight and obese adolescents[14,15,39,56,48,66] did not find any changes in lipid profile[39,48,56] or did not report any findings at postintervention.[14,66] From the literature presented to date, there seems to be no added effect of resistance exercise training on lipid profile in the small number of studies published on obese youth. A diet component may be necessary to initiate such changes in lipids, and these study populations may not have had dyslipidemic profiles at baseline of the intervention, and thus may have lacked room for improvement following a resistance exercise training intervention.

Summary

There is extensive evidence to show that aerobic exercise training improves body composition and metabolic fitness, but the evidence is not as conclusive in resistance exercise interventions with obese youth. Resistance exercise training can be safely performed by youth with proper supervision and instruction. Resistance training increases lean body mass and muscular strength, and modestly decreases percent body fat, but the effects on abdominal adiposity remain inconclusive in obese youth. The effects of resistance training on abdominal adiposity, flexibility, muscular power, glycemic control, blood pressure, and the lipid profile are inconsistent; the impact may be greater in individuals with impaired metabolic profiles at baseline. One small randomized controlled pilot study showed small decreases in fat mass with a combined aerobic and resistance training intervention. Interpretation of results from uncontrolled before and after studies that suggest that resistance training is an effective method to reduce cardiometabolic risk in youth is complicated by coexisting changes in growth and maturation. The independent effect of resistance exercise training in youth may confer health benefits by improving body composition and musculoskeletal fitness, while other metabolic parameters require further investigation with additional, better-designed studies in the future.

Future Directions

It is important to consider factors that influence the commencement and continuation of resistance training programs with overweight and obese youth to maximize adherence and long-term health implications. Pescud et al[73] examined this question and found that the most relevant factors were the opportunity to build strength, improve fitness, and have parental support to initiate a program. Motivators for continuation among the children were weight loss and improved confidence, along with positive peer and trainer interactions and continuous parental support. Future research should include exercise interventions that avoid barriers to participation and consider the factors that increase commencement and continuation.

There is a paucity of well-controlled studies investigating the effects of resistance exercise training on health-related measures in overweight and obese adolescents. Future studies should examine the effects of resistance training alone and in combination with aerobic training on abdominal adiposity, cardiorespiratory fitness, musculoskeletal fitness (comprehensive assessment of muscular strength, endurance, muscular power, and flexibility), and metabolic profile (insulin sensitivity, glucose tolerance, blood pressure, and lipid profile). Randomized controlled trials with larger culturally diverse samples of older overweight and obese youths (aged 13–18 years), of longer duration (> 16 weeks), and incorporating a higher frequency of exercise sessions (> 2 sessions/wk) are important aspects to consider when designing future interventions with overweight and obese adolescents.

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Conflict of Interest Statement

Angela S. Alberga, MSc, Ronald J. Sigal, MD, MPH, and Glen P. Kenny, PhD disclose no conflicts of interest.

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CHAPTER III: METHODS

MANUSCRIPT 4: Healthy Eating, Aerobic and Resistance Training in Youth (HEARTY): Study Rationale, Design and Methods

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Permission was granted to include the published version of this article in this dissertation (Appendix).

Statement of contributions of collaborators:

A.S. Alberga carried out the bibliographic search, article screening, and drafted and edited the manuscript. R.J. Sigal is the overall leader of the HEARTY trial, R.J. Sigal, G. Goldfield, G.P. Kenny were the main designers of the trial. R.J. Sigal, G.P. Kenny, G. Goldfield, and S. Hadjiyannakis (HEARTY co-Principal Investigators) and, D. Prud'homme, H. Tulloch, R. Gougeon and G. Wells (co-investigators) provided analytical input and helped draft and edit the manuscript. P. Phillips was the HEARTY research coordinator, provided analytical input and helped draft and edit the manuscript.

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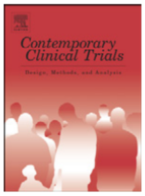

Healthy eating, aerobic and resistance training in youth (HEARTY): Study rationale, design and methods

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ABSTRACT

Purpose: The objective of the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) trial (ClinicalTrials.Gov # NCT00195858) was to examine the effects of resistance training, with and without aerobic training, on percent body fat in sedentary, post-pubertal overweight or obese adolescents aged 14–18 years. This paper describes the HEARTY study rationale, design and methods.

Methods: After a 4-week supervised low-intensity exercise run-in period, 304 overweight or obese adolescents with a body mass index ≥ 85th percentile for age and sex were randomized to 4 groups for 22 weeks (5 months): diet + aerobic exercise, diet + resistance exercise, diet + combined aerobic and resistance exercise, or a diet only waiting-list control. All participants received dietary counseling designed to promote healthy eating with a maximum daily energy deficit of −250 kcal.

Outcomes: The primary outcome is percent body fat measured by Magnetic Resonance Imaging. Secondary outcomes include changes in anthropometry, regional body composition, resting energy expenditure, cardiorespiratory fitness, musculoskeletal fitness, cardiometabolic risk markers, and psychological health.

Summary: To our knowledge, HEARTY is the largest clinical trial examining effects of aerobic training, resistance training, and combined aerobic and resistance training on changes in adiposity and cardiometabolic risk markers in overweight and obese adolescents. The findings will have important clinical implications regarding the role that resistance training should play in the management of adolescent obesity and its co-morbidities.

1. Introduction

It has been shown that 80% of obese adolescents become obese adults, and thus intervening during adolescence is critical to prevent adult obesity [1]. Meta-analytic reviews demonstrate that exercise is a critical component in the management of pediatric obesity and its co-morbidities [2,3]. Due to obese children's excess weight, low physical fitness, and the weight-bearing nature of most types of aerobic exercise, obesity in youth makes adherence to aerobic exercise very difficult [3,4] but may pose less of a problem for resistance training.

There is strong evidence supporting the benefits of resistance training on increasing lean body mass [5–8] and

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muscular strength in post-pubertal obese adolescents [5,7–10]. However, these studies yielded mixed and inconclusive results on adiposity, glucose tolerance and lipid measures and are limited by small sample sizes [6–14], lack of a non-exercising control group [6,7,12,14], no comparison to an aerobic-only group [6,7,9–11] and exercise intervention periods (8–16 weeks) too short to determine the optimal effects of resistance exercise on body composition [6–13]. Furthermore, none of the above studies used Magnetic Resonance Imaging (MRI) to assess total and regional body composition. In addition to these methodological weaknesses, recent reviews [15,16] highlighted the need for more robustly controlled studies to examine the *independent and incremental* effect of resistance training on body composition and cardiometabolic health in obese youth.

The primary objective of the HEARTY trial is to determine the effects of 6 months of supervised diet + aerobic training, diet + resistance training, diet + combined aerobic and resistance training, or diet-only control on percent body fat measured by MRI in previously sedentary post-pubertal overweight or obese youth aged 14–18 years. The secondary objectives of the study are to examine the effects of each exercise modality on changes in body composition [lean body mass, abdominal visceral and subcutaneous fat, body mass index, waist and hip circumference]; traditional and non-traditional cardiovascular risk factors. Other secondary outcome measures include resting energy expenditure, cardiorespiratory and musculoskeletal fitness, and psychosocial functioning (quality of life, body image, mood and self-esteem). This report describes the HEARTY study design and methods.

2. Methods

2.1. Design

HEARTY was a randomized controlled trial with a parallel group design conducted at a single site. After a 4-week run-in period to assess compliance, participants were randomized to 22 weeks of diet plus either aerobic, resistance, combined aerobic and resistance exercise or a diet-only control.

We randomized 304 sedentary post-pubertal (Tanner stages 4–5) overweight or obese adolescents aged 14–18 years. The CONSORT diagram is shown in Fig. 1. The trial began in March 2005 and was completed in June 2011. The primary sources of recruitment included advertisements in city busses (49%), from the obesity/endocrinology clinic at the Children's Hospital of Eastern Ontario, family physicians and pediatricians in the community (25%), word of mouth referrals (11%), posters and print advertisements (10%), and small portions from local radio campaigns (4%) and schools (2%). Individuals interested in participating in the study contacted the research coordinator for more information and were screened for inclusion. The coordinator reviewed the study protocol, inclusion/exclusion criteria (Table 1) and obtained informed consent according to the Tri-Council Policy Statement Guidelines [17]. The main

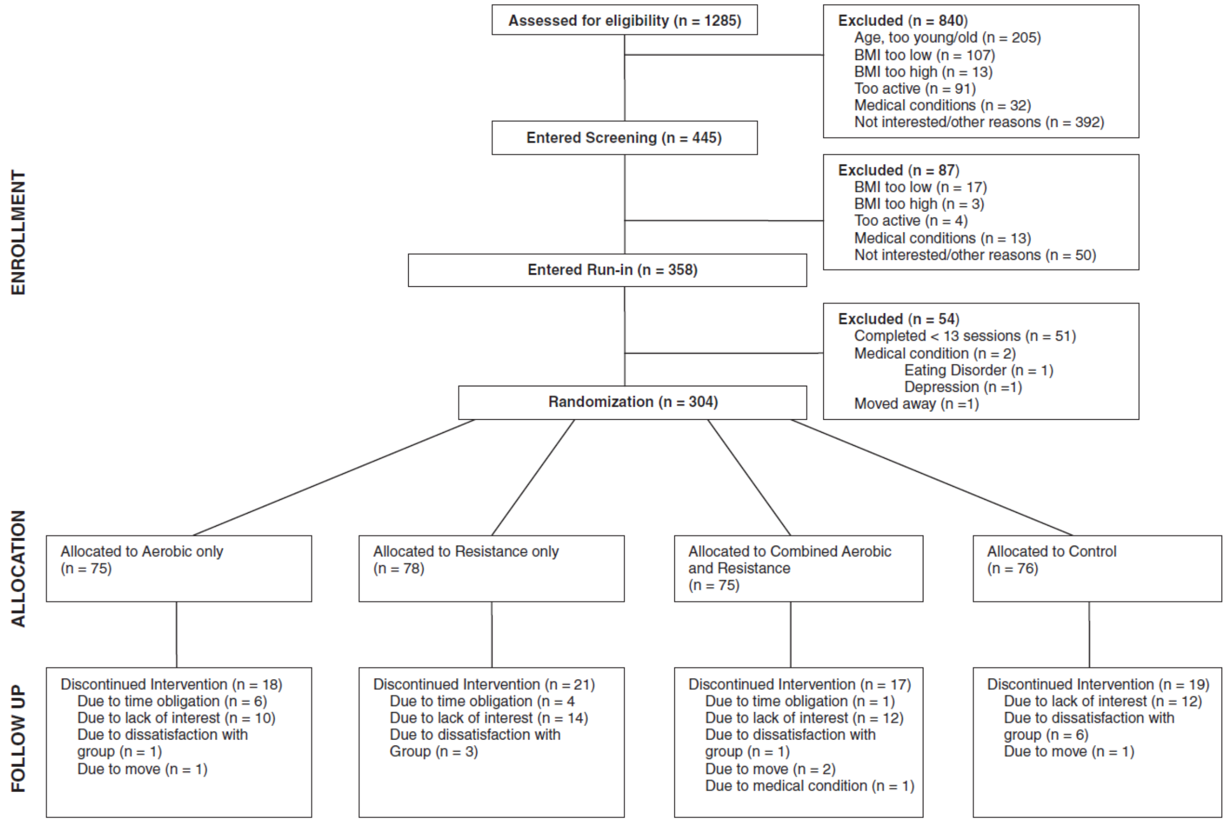

Fig. 1. HEARTY screening, enrolment and follow-up.

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
1. Body Mass Index≥95th percentile for age, and sex (http:www.cdc.gov/growthcharts) AND/OR≥85th percentile for age/sex with an additional diabetes risk factor: fasting glucose≥6.0 mmol/L fasting, 2-hour plasma glucose 7.8–11 mmol/L after 75 g oral glucose (impaired glucose tolerance), fasting triglycerides>1.7 mmol/L, fasting plasma insulin>105 pmol/L, HDL-C<0.9 mmol/L, LDL-C>3.0 mmol/L, total cholesterol/HDL-C>90th percentile, or first degree relative with type 2 diabetes 2. Waist circumference was required to be ≥75th percentile for age and sex [31] so participants with high BMI primarily because they were muscular would not qualify 3. Age 14–18 years at time of screening 4. Post-pubertal (Tanner stage IV or V) [32] 5. Sedentary for at least 4 months prior to enrolment	1. Participation during the previous 4 months in a regular program of exercise or aerobic sports≥2 times per week for at least 20 min per session 2. Diabetes mellitus 3. Body weight over 159 kg, and/or BMI>45 kg/m^2, exceeding capacity of the MRI machine 4. Use of any performance-enhancing medication 5. Use of medication, or herbal supplement likely to affect body composition, lipids or glucose metabolism. Metformin use was permitted if participants were on metformin prior to enrollment and the dose was not altered throughout the trial. We asked that initiation of, or changes in antihypertensive, lipid- and glucose-lowering medications would not be made during the intervention period unless considered medically imperative. 6. Significant weight change (increase or decrease of≥5% during the two months before enrolment) 7. Uncontrolled hypertension: blood pressure >150 mm Hg systolic or >95 mm Hg diastolic in sitting position 8. Activity restrictions due to disease: unstable cardiac or pulmonary disease, significant arthritis 9. Other illness (i.e. eating disorders/clinical depression) judged by the subject or study physician to make participation in this study inadvisable 10. Unwillingness/lack of availability to attend exercise and/or nutrition sessions at scheduled times and locations 11. Significant cognitive deficit resulting in inability to understand or comply with instructions 12. Pregnancy at the start of the study, or intention to become pregnant in the next year 13. Inability to communicate in English or French 14. Unwillingness of participant and/or guardian to sign informed consent

inclusion criteria were: sedentary post-pubertal (Tanner stages IV–V) adolescents aged 14–18 years with body mass index (BMI)≥95th percentile for age, and sex (http://www.cdc.gov/growthcharts) or ≥85th percentile for age/sex with an additional diabetes or cardiovascular disease risk factor (Table 1). A parent or guardian was asked to co-sign the consent form of any participant below the age of 16 years. This study received approval from the Research Ethics Boards at the Children's Hospital of Eastern Ontario and the Ottawa Hospital.

2.2. Baseline assessment

The research coordinator performed a complete medical, drug, and physical activity history, and focused physical examination. In addition, pubertal growth and development, history of dieting, binge eating, eating disorders, weight fluctuation over time, and time spent in sedentary activities (television, video, computer/video games, Internet) were evaluated by a clinical interview. Participants were given 3-day logs to report physical activity and dietary intake. On a separate visit, fasting blood tests and psychosocial questionnaires were completed. Over a series of baseline visits, body composition, resting metabolic rate, cardiorespiratory and musculoskeletal fitness were measured before participants began the run-in program. The testing timeline for all measurements is presented in Table 2.

2.3. Study protocol

2.3.1. Run-in phase (weeks 1–4)

Once baseline testing was complete, participants began the 4-week run-in phase to test exercise session compliance. The exercise protocol for run-in is outlined in Table 3. During run-in all participants engaged in low-intensity aerobic and resistance exercise for 4 sessions per week. Participants received individual supervision by a personal trainer twice per week to ensure they performed each exercise correctly and safely.

To qualify for randomization, participants had to attend at least 13 out of 16 prescribed sessions (>80% adherence) during run-in. Upon completion of the run-in, participants (N=304) were randomized into 1 of 4 groups: diet+aerobic (n=75), diet+resistance (n=78), diet+combined aerobic and resistance (n=75), or diet-only control (n=76). Randomization was stratified by degree of overweight (85th–95th BMI percentile or ≥95th BMI percentile) and sex and done in blocks randomly varying between 4 or 8 participants. Randomization sequences were prepared by an independent statistician and entered into a telephone based central randomization program (IVRS, VBvoice v5.3, Pronexus, Ottawa, Canada). The exercise specialist used the randomization program and informed participants of their group assignments, allowing the research coordinator to remain blinded.

2.3.2. Intervention phase (weeks 5–26)

2.3.2.1. Diet— common to all 4 groups. All participants and the individuals in their households most involved in food preparation attended an initial visit with the dietitian to discuss weight and diet history, fast food consumption and current eating habits. Baseline resting metabolic rate measurements were used to determine energy needs. Dietary goals were collaboratively established by the dietitian and each participant. Visits with the dietitian occurred at baseline,

Table 2
Testing timeline.

Randomization

Testing variables	Baseline assessments						Intervention	
	Phone screening	Screening visit 1	Visit 2	Visit 3	Visit 4	Run-in period (4 week)	3-month	6-month
Inclusion and exclusion criteria	X							
Informed consent form		X						
Medical history (major)		X					X	X
Complete physical exam		X						X
Waist and hip circumference		X					X	X
Weight/height and BP		X					X	X
CBC			X					
Liver enzymes			X					
TSH			X					
Serum creatinine			X					
Serum Testosterone			X					
Fasting plasma glucose			X				X	X
Hemoglobin A1C			X					X
Fasting plasma insulin			X				X	X
Fasting plasma lipid profile			X				X	X
High sensitivity C-reactive protein (frozen)			X					X
Apolipoprotein B (frozen)			X					X
Apolipoprotein A1(frozen)			X					X
FFA — Free Fatty Acids (frozen)			X					X
Samples for future testing			X				X	X
OGTT			X					X
3-day food diary			X				X	X
Psychological Questionnaires			X				X	X
Pedometer-7 day log			X				X	X
Review activity log			X				X	X
MRI scan				X				X
VO_{2peak}					X			X
Resting energy expenditure (RMR)					X			X
Dietary assessment						X	X	X
Musculoskeletal fitness testing						X	X	X
Exercise education						X		X
Exercise prescription						X		D
Orientation to gym						X		D
Supervision of exercise sessions						X	E	E
Exercise logs						X	E	X

LEGEND
X = All participants
D = Diet only
E = All 3 exercise groups
M = Month

3 and 6 months, with additional support provided by phone at 6 weeks and 4 months. Participants also attended a two-hour small group (n = 12) session (during run in only; prior to randomization) covering various topics: barriers in achieving healthful eating and solutions to overcome them, taste panels of fruits and vegetables, label reading, healthful snacks, and healthier eating at fast food outlets. The recommended macronutrient energy distribution was 15–20% protein, 50–55% carbohydrates and 30% fat [18]. Dietary recommendations were individually tailored to reduce energy intake by

Table 3
Run-in training program.

Week #	Aerobic training			Resistance training			
	Duration (min/day)	Intensity (% HR_{max})	Frequency (sessions/week)	Sets	Reps	Weight (RM)	Frequency (sessions/week)
1	15	65	4	1	15	15	4
2	20	65	4	2	15	15	4
3	25	65	4	2	15	15	4
4	30	65	4	3	15	15	4

Abbreviations: % HR_{max} = Percentage of the Maximum Heart Rate achieved from the maximal exercise test to assess cardiorespiratory fitness ($\dot{V}O_{2peak}$); REPS = Repetitions; RM = Repetition Maximum (the 15th repetition is the last repetition that can be done with proper technique and form) approximately 250 kcal daily. Dietary prescription was the same in all 4 groups.

2.3.2.2. Exercise protocol: common elements to all 3 exercise groups. In addition to the dietary program described, participants in all of the three exercising groups were asked to attend the gym 4 times per week. The cost of gym memberships was covered by the HEARTY grant for the duration of the intervention phase. A certified fitness trainer was present for scheduled sessions at each of the gym locations (4 in Ottawa and 2 in Gatineau). The participants were provided with a binder that included a description of the HEARTY exercise program with illustrations. The trainers ensured proper technique, safety and appropriate progression. Personal trainers provided modified exercise options if participants experienced any muscle soreness or discomfort from the exercise program.

Initial workloads and intensity were based on performance during the baseline cardiorespiratory and strength fitness testing (see measurement procedures below). After randomization, the exercise specialist met with each participant twice weekly for the 4-week run-in, then every 2 weeks for the remainder of the program. The exercise intervention program is described in Tables 4 and 5. Each session began with a 5–10 min warm-up consisting of light exercises, and ended with a cool-down (5–10 min of light exercises and stretching). The exercise specialist monitored attendance and appropriate progression by reviewing sign-in sheets, electronic scanning of membership cards and completion of exercise logs.

Table 4
Aerobic training program.

Week no.	Frequency (days/week)	Work load	Work load
		Sessions 1 and 3	Sessions 2 and 4
		Duration/intensity (%HR$_{max}$)	Duration/intensity (%HR$_{max}$)
5	4	20 min 70%	10 min 75%/10 min 65%
6	4	20 min 70%	15 min 75%/10 min 65%
7	4	25 min 70%	20 min 75%/10 min 65%
8	4	25 min 75%	20 min 75%/10 min 70%
9	4	25 min 75%	20 min 75%/15 min 70%
10	4	25 min 75%	20 min 75%/10 min 65%/5 min 75%
11	4	25 min 75%	20 min 75%/10 min 65%/10 min 75%
12	4	25 min 80%	20 min 75%/10 min 65%/15 min 75%
13	4	25 min 80%	15 min 80%/10 min 65%/10 min 80%
14	4	25 min 80%	20 min 80%/10 min 65%/10 min 80%
15	4	30 min 75%	20 min 80%/10 min 65%/15 min 80%
16	4	30 min 75%	20 min 80%/10 min 65%/15 min 80%
17	4	30 min 75%	20 min 80%/10 min 65%/15 min 80%
18	4	30 min 75%	25 min 80%/10 min 65%/10 min 80%
19	4	30 min 80%	25 min 80%/10 min 65%/10 min 80%
20	4	30 min 80%	25 min 80%/10 min 65%/15 min 80%
21	4	35 min 80%	25 min 80%/10 min 65%/15 min 80%
22	4	35 min 80%	25 min 80%/10 min 65%/10 min 80%
23	4	35 min 80%	20 min 85%/10 min 65%/10 min 85%
24	4	35 min 80%	20 min 85%/10 min 65%/15 min 85%
25	4	35 min 80%	20 min 85%/10 min 65%/15 min 85%
26	4	35 min 80%	20 min 85%/10 min 65%/10 min 85%

Abbreviations: % HR$_{max}$ = Percentage of the Maximum Heart Rate achieved from the maximal exercise test to assess cardiorespiratory fitness ($\dot{V}O_{2peak}$).

Table 5
Resistance training program.

Week no.	Frequency (days/week)	Work load			Work load	
		Sessions 1 and 3			Sessions 2 and 4	
		# of repetitions per set			# of repetitions per set	
		1	2	3	1	2
5	4	15	15	15	15	15
6	4	15	15	15	15	15
7	4	15	15	15	15	15
8	4	12	12		15	15
9	4	12	12		15	15
10	4	12	12	12	15	15
11	4	12	12	12	15	15
12	4	10	10	10	15	15
13	4	10	10	10	12	12
14	4	10	10	10	12	12
15	4	8	8	8	12	12
16	4	8	8	8	12	12
17	4	8	8	8	12	12
18	4	8	8	8	10	10
19	4	8	8	8	10	10
20	4	8	8	8	10	10
21	4	6	6	6	10	10
22	4	6	6	6	10	10
23	4	6	6	6	10	10
24	4	6	6	6	10	10
25	4	6	6	6	10	10
26	4	6	6	6	10	10

2.3.2.3. Diet + aerobic training group. After the 4-week run-in period, participants randomized to the aerobic training group underwent a 22-week program (Table 4) wherein the exercise intensity and duration increased progressively to a maximum of 45 min per session. Exercise was performed on a cycle ergometer, elliptical or treadmill and participants were free to vary the machine(s) used. Exercise intensity was standardized using heart rate monitors (Polar Electro Oy, Kempele, Finland).

2.3.2.4. Diet + resistance training group. After the 4-week run-in period, participants randomized to the resistance training group underwent the program outlined in Tables 5 and 6. The duration of each session progressed to a maximum of about 45 min.

Exercises were primarily performed on weight machines, and when required with dumbbells (lateral raise, shrugs, bicep curls, front raise, preacher curl, dumbbell pullover) or by using one's own body weight as resistance (lunges, sit-ups and abdominal crunches). Participants alternated among exercises from groups A1, A2, B1 and B2 shown in Table 6. Participants were asked to rest for ~2 min between sets and were instructed on proper breathing techniques.

2.3.2.5. Diet + combined aerobic and resistance training group. This group performed the full exercise programs done by both the aerobic and resistance training groups (Tables 4 and 5) during each session for a total of 4 times per week for a maximum of 90 min per session.

2.3.2.6. Diet-only control group. The control group followed the same eating plan as those in the exercise groups. After completing the run-in phase, they reverted to their pre-study activity levels for 22 weeks. Once the post-intervention measurements were assessed, participants in the control group were given the option to begin an exercise program (with a free gym membership) for the subsequent 6-months.

3. Measurements

The timeline of all measurements is displayed in Table 2. Baseline visits included all testing sessions before the exercise run-in period began. To encourage adherence and retention, participants completing all measurement assessments (0, 3, and 6 months) received a $50 gift certificate. In addition, participants who maintained good compliance (≥70% of sessions attended) obtained a free gym membership renewal for a subsequent 6-month period (post-intervention).

3.1. Primary outcome

The primary outcome was percent body fat assessed by MRI. Body composition was assessed by MRI (General Electric, 1.5 Tesla scanner, version signa 11 with echo speed gradients, Milwaukee, WI) at baseline and at 6-months. The participants lay prone during the acquisition of 42–48 whole body cross-sectional images using established protocols by Ross et al. [19,20]. The raw MRI data collected were then analyzed using Slice-o-matic software V. 4.3 (Tomovision, Montreal, QC, Canada) to quantify total and regional body composition.

3.2. Secondary outcomes

3.2.1. Anthropometry

The research coordinator, blind to group assignment, measured BMI, waist and hip circumference at baseline, 3 and 6 months post-intervention. Weight (kg) and height (cm) were measured using a Health O Meter manual scale (Health O Meter, Continental Scale Corp., Bridgeview, ILL). BMI was calculated by $\text{BMI} = [\text{weight (kg)}]/[\text{height (m)}^2]$. Waist circumference was measured at the middle distance between the last floating rib and the iliac crest using a retractable ergonomic measuring tape (Seca GmBH & Co Kg, Hamburg, Germany). Hip circumference was measured at the widest point, over the buttocks.

3.2.2. Background physical activity

Participants were asked to wear pedometers (Yamax DIGIWALKER SW-700, Yamax Corporation, Tokyo, Japan) for one week at baseline, 3, and 6 months except when showering or sleeping. Leisure time physical activity was defined as the mean daily total step count for the days the pedometer was worn, excluding steps during scheduled exercise sessions. Participants recorded the physical activities performed over 3 days at baseline, 3, 6 and 12 months using the Past Day Physical Activity recall, a valid self-report measure of physical activity in youth (including obese youth) [21].

3.2.3. Energy intake

Energy intake was assessed using a 3-day food log at baseline, 3, and 6 months, which was also used by the dietitian to teach diet adequacy and identify energy-dense foods and those of poor nutritional value. The logs were analyzed with food composition analysis software (The Food Processor SQL 2006, ESHA Research, Salem, OR) to determine total energy intake and separate macronutrient intake for carbohydrate, protein and fat for each participant.

3.2.4. Resting energy expenditure (REE)

Resting metabolic rate tests were conducted at baseline and at 6 months. Participants arrived at the laboratory between 7:00 am and 11:00 am after a 12-hour fast. Oxygen consumption was measured by indirect calorimetry using an automated metabolic system (MOXUS Modular Metabolic System, AEI Technologies Naperville, IL, USA) for a 20-minute data collection period. Total resting energy expenditure [REE (kcal/day)] was then calculated using the Weir equation [22].

3.2.5. Cardiorespiratory fitness

Peak oxygen uptake ($\dot{V}O_{2peak}$) was assessed by indirect calorimetry following the REE test at baseline and at 6-months. A modified Balke and Ware incremental treadmill test [23,24] was utilized. Criteria for $\dot{V}O_{2peak}$ test termination included a plateau in $\dot{V}O_2$ despite an increase in work rate, and/or the participant's desire to stop. The highest relative rate of oxygen consumption achieved was considered to be the $\dot{V}O_{2peak}$. The maximal heart rate achieved from the baseline $\dot{V}O_{2peak}$ test was used to determine initial workload and exercise intensity for the aerobic exercise program (Table 3) of the study.

3.2.6. Strength testing

An 8-repetition maximum (8-RM) test was performed on the bench press, seated row and leg press machines at 0, 3 and 6-months. The test was administered in the gym by the exercise specialist. The results of the 8-RM test were used to establish the work intensity for the resistance exercise program (Table 5).

3.2.7. Musculoskeletal fitness

Five musculoskeletal fitness tests were conducted at baseline, 3 and 6 months to assess muscular strength, muscular endurance and flexibility according to established protocols by the Canadian Society for Exercise Physiology [25]. The tests were conducted in consecutive order: grip strength, push-ups, sit and reach, partial curl-up and vertical jump.

3.2.8. Traditional cardiovascular disease risk factors

All of the blood measurements (Table 1), except the Oral Glucose Tolerance Test (OGTT) (2-h post load plasma glucose), were done at baseline, 3 and 6 months under 12-hour fasted conditions and participants had refrained from vigorous physical activity or the use of anti-inflammatory or other medications 24 h before the testing. These include resting blood pressure, fasting plasma glucose, insulin and lipid concentrations, Hemoglobin A1c (HbA1c), and 2-hour glucose after the OGTT. All fasting blood samples were drawn prior to beginning the OGTT.

HbA1c was measured using turbidimetric immunoinhibition, and total cholesterol, high-density lipoprotein (HDL) cholesterol, and triglyceride levels were measured by using enzymatic methods on a Beckman-Coulter LX20 analyzer (Beckman Instruments, Brea, California). Low-density lipoprotein (LDL) cholesterol levels were calculated using the Friedewald equation [26].

After a 12-hour overnight fast, venous blood samples of plasma glucose were obtained from participants before and 2 h after they ingested a 75 gram glucose solution (OGTT). Insulin resistance was also estimated from fasting plasma glucose and fasting insulin concentrations using the Homeostatic Model Assessment (HOMA) [27].

3.2.9. Non-traditional cardiovascular disease risk factors

Apolipoproteins-A1 and -B (ApoA1 and ApoB) were measured using immunoturbidimetric assays (Beckman Coulter Unicel®DxC600 Synchron® Clinical System and Beckman reagents Beckman Coulter, Inc., Brea, California). High-sensitivity C-reactive protein (CRP) was measured using highly sensitive Near Infrared Particle Immunoassay rate methodology (Beckman Coulter Unicel®DxC600 Synchron® Clinical System and Beckman reagents Beckman Coulter, Inc., Brea, California). Non Esterified Fatty Acids (NEFA) were measured using an enzymatic colorimetric method (Randox Laboratories, Antrim, United Kingdom) and analyzed using the Beckman Coulter Unicel®DxC600 Synchron® Clinical System.

3.2.10. Psychological health

Questionnaires (Table 7) were administered at baseline, 3, and 6 months to assess quality of life, body image, mood and self-esteem.

4. Biostatistical considerations

4.1. Sample size calculation

A meta-analysis of exercise interventions by Lemura and Maziekas (2002) [28] found that the combination of resistance and aerobic exercise was significantly more effective in reducing percent body fat in obese youth compared to aerobic exercise alone (effect sizes of 1.2 vs. 0.58). These results suggest that the addition of resistance exercise to aerobic exercise exercise provides an incremental benefit of 0.62 standard deviations beyond that derived from aerobic alone.

To assess the effects of exercise modality on changes in percent body fat (primary outcome) over time, assuming an effect size of 0.6 SD for the least powered planned comparison, we calculated a sample size of 248 participants (62 per group) completing the intervention would allow 80% power for each of the 4 comparisons tested simultaneously (alpha = 0.0125 for each comparison, overall alpha 0.05). We randomized 304 participants to allow for 18–20% dropout similar to the rates observed in previous randomized controlled trials designed to increase physical activity in obese youth [29] and in adults with type 2 diabetes [30].

4.2. Primary analysis

Analyses will be intention-to-treat. We will use linear mixed-effects modeling for repeated measures over time with percent body fat as the dependent variable and effects for time (baseline, 3-months, 6-months), group [aerobic (A), resistance (R), combined aerobic + resistance (AR), Control], and time by group interaction, with age, sex, and BMI as covariates, with an unstructured covariance matrix. Within the mixed model, 95% confidence intervals and p-values for specific intergroup contrasts (R vs. Control; AR vs. A; A vs. Control; AR vs. R), and for change in percent body fat over time within each group will be estimated. For continuous secondary outcomes, including anthropometric, physiological and psychological outcomes, we will use the same procedure as for the primary analysis. Linear mixed modeling uses all available data, and only available data, so there is no need to impute missing data.

We will also conduct stratified analyses for all outcomes above, by sex and by degree of overweight (85-95th percentile versus >95th percentile of BMI z-score). We will use linear mixed modeling to assess the extent to which the effects of exercise group assignment on each outcome are mediated by intermediate effects such as proportion of prescribed sessions attended, changes in body composition and energy expenditure, changes in $\dot{V}O_{2peak.}$, changes in strength, HOMA insulin resistance, serum testosterone, dietary composition (total energy consumed), percent of calories from fat, carbohydrates and protein. These covariates will be entered in mixed models singly and in combinations, to elucidate which have the greatest effects. For these analyses, total daily energy consumed, percent calories from fat, carbohydrate and protein will be calculated as the subject-specific mean values derived from the 3-day food diaries.

In addition to the intention-to-treat analyses, we will conduct per-protocol analyses including only those participants who completed at least 70% of prescribed exercise sessions and all follow-up measures.

5. Discussion

HEARTY is the largest randomized controlled trial testing the effects of resistance training, with or without aerobic training, in overweight and obese adolescents, thus allowing an assessment of the absolute and incremental effects of resistance training across a wide variety of health outcomes. None of the ongoing trials registered in ClinicalTrials.gov or ISRCTN (both accessed 24/11/2011) is of the same size or scope as the HEARTY trial, and none will be able to achieve all or most of the HEARTY trial's objectives. A large, adequately-powered and well-designed trial like HEARTY was needed to determine the effectiveness of resistance training, and the incremental impact of combined aerobic + resistance training versus either type of exercise alone, on body composition, muscular strength and fitness and cardiometabolic and psychological health in overweight and obese adolescents. At this writing, data analyses are in progress but not complete; results will be presented in separate publications. Our findings will have considerable clinical implications for the role that resistance exercise plays in the management of adolescent obesity and its co-morbidities. Moreover, the effects of resistance training on body composition and health may inform public health exercise guidelines and school-based physical education curricula in attempt to reduce the economic, medical, and psychosocial burden of obesity in youth.

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Appendices

Table 6
Resistance training exercises.

A1	A2	B1	B2
Bench press	Incline bench press	Squat	Leg press
Chest fly	Incline chest fly	Seated leg curl	Leg extension
Lateral raise	Shoulder press	Front lateral pull down	Dumbbell pullover
Shoulder shrugs	Front raise	Seated row	Seated row
Bicep curl	Preacher curl	Lunge	Lying leg curl
Tricep press	Assisted tricep dips	Straight leg raise	
Abdominal crunches	Sit-ups	Abdominal crunches	

Table 7
Psychological questionnaires administered.

Psychological construct	Questionnaire used
Quality of Life	Pediatric Quality of Life (PEDSQL-Adolescent version) [33], a 23-item self-report consisting of generic core scales encompassing physical functioning (8-items), emotional functioning (5-items), social functioning (5-items), and school functioning (5-items). A total scale score is derived by the mean of all 23 items, as is a psychosocial health summary scored (derived from mean of items in the emotional, social, and school functioning subscales).
Body Image	Multidimensional Body-Self Relations Questionnaire (MBSRQ) [34]. This is a 34-item measure that consists of 5 subscales; appearance evaluation, appearance orientation, overweight preoccupation, self-classified weight, and the body areas satisfaction scale.
Mood	Two questionnaires used: 1. Profile of mood states — Adolescent version (POMS-A, aka Brunel Mood Scale) [35], a 24-item inventory adapted from the original 65 item POMS inventory developed by McNair, Lorr, Droppleman (1971) [36] The POMS-A has the same 6 mood subscales as the original POMS; fatigue, anger, tension, confusion, vigor, and depression. 2. Child Depression Inventory [37]. This is a 27-item questionnaire which asks respondents (6–17 years old) to endorse statements about themselves reflecting cognitive, behavioral and somatic symptoms of depression. Items are rated on a 3-point scale indicating symptom severity (i.e., 0 = no presence of symptom and 2 = highest severity possible). Total scores on the CDI can range from 0 to 52, with higher scores indicative of greater reports of depressive symptomatology. This inventory provides a total depression score, plus 5 factor scores: negative mood, interpersonal problems, ineffectiveness, anhedonia, and negative self-esteem.
Self-esteem	Harter Physical Self-Perceptions Profile for Children (PSPP) [38,39]. A study of children's physical self-perceptions using an adapted physical self-perception profile questionnaire. This is a 36-item self-reporting scale developed to determine Adolescent's domain-specific judgments of their competence, as well as a global perception of their worth or esteem as a person. It contains six separate subscales consisting of five specific domains: 1) sport competence (athletic ability, ability to learn sports); 2) perception of physical condition and fitness; 3) perception of an attractive body (confidence in personal appearance); 4) perception of physical strength; and 5) physical self-worth, as well as a general domain of global self-worth.

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CHAPTER IV: RESULTS

Preamble: Manuscripts 5, 6, 7 and 8

By agreement among the HEARTY investigators, the primary results of the HEARTY study (Manuscript 5) must be accepted for publication before secondary outcomes proposed for my dissertation (Manuscripts 6, 7 and 8) are submitted for publication.

The following Manuscript 5 details the effects of the HEARTY trial on percent body fat (the primary outcome) and cardiometabolic risk markers.

The subsequent Manuscripts 6, 7 and 8 discuss the effects of the HEARTY trial on the secondary outcomes proposed for this doctoral thesis: abdominal fat distribution and cardiovascular disease risk markers (Manuscript 6), resting metabolic rate (Manuscript 7) and cardiorespiratory and musculoskeletal fitness (Manuscript 8) in obese adolescents.

MANUSCRIPT 5: Effects of aerobic training, resistance training, or both on percent body fat and cardiometabolic risk markers in obese adolescents: the HEARTY trial

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Statement of contributions of collaborators:

A.S. Alberga assisted with participant recruitment, screening, informed consent visits, study coordination, physical training and was responsible for the Magnetic Resonance Imaging (MRI) body composition analysis, bibliographic search, article screening, and drafted and edited the manuscript.

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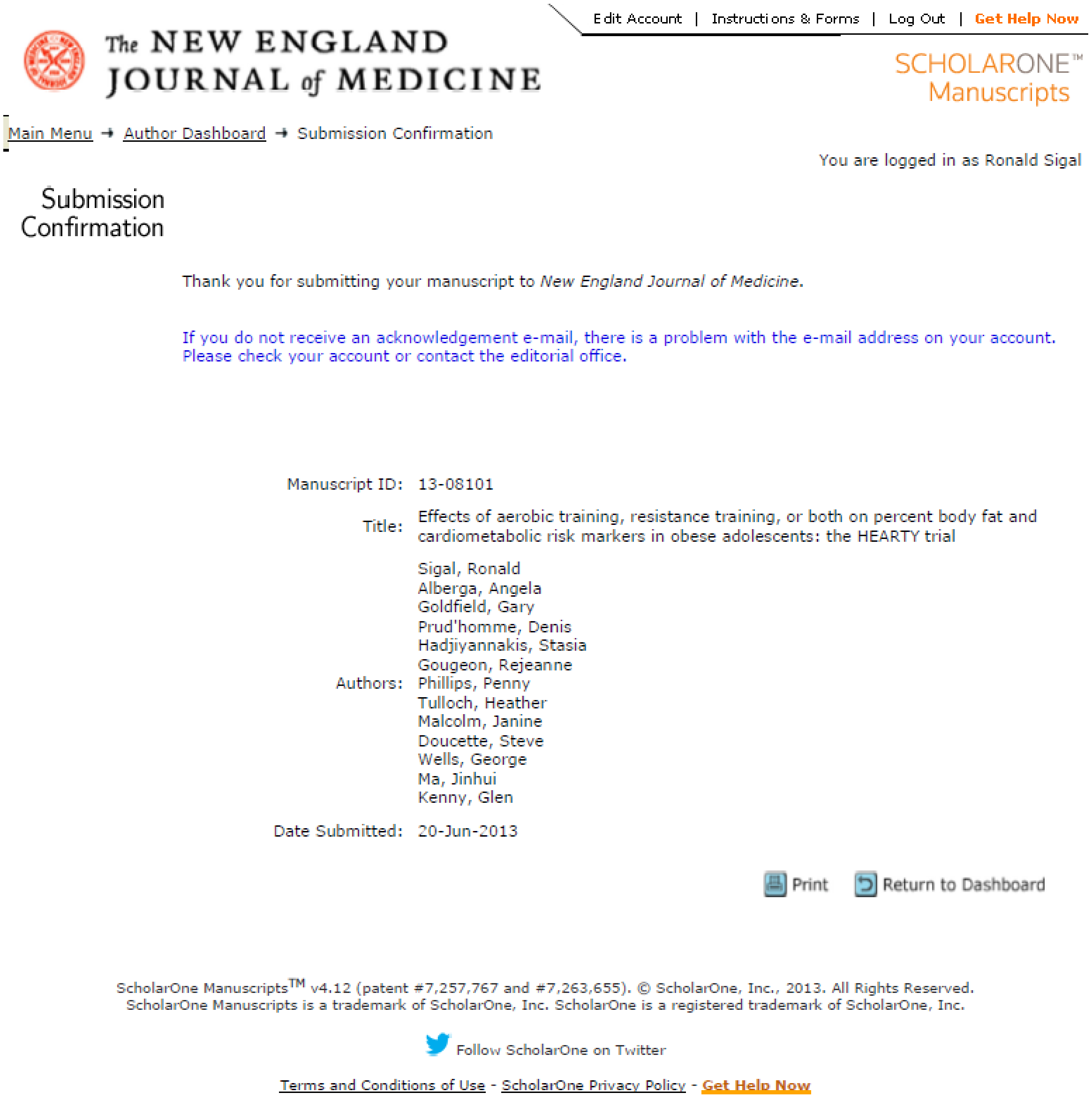

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Effects of aerobic training, resistance training, or both on percent body fat and cardiometabolic risk markers in obese adolescents: the HEARTY trial

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ABSTRACT

BACKGROUND: Exercise is recommended for obese adolescents, but there is little evidence on which exercise modality is optimal.

METHODS: A randomized, controlled trial examining the effects of different exercise modalities on percent body fat (%BF) by Magnetic Resonance Imaging in physically inactive, overweight or obese adolescents aged 14-18y. After a 4-week supervised low-intensity exercise run-in, 304 adolescents with body mass index ≥ 85th percentile for age and sex were randomized to 4 groups for 22 weeks: Aerobic training, Resistance training, Combined aerobic and resistance training, or non-exercising Control. All participants received dietary counseling with a maximum daily energy deficit of 250 kcal.

RESULTS: Decreases in %BF were 0.3% in controls, 1.1% in Aerobic ($p=0.059$ versus control), and 1.6% in Resistance ($p=0.002$ versus control). The 1.4% decrease in Combined did not differ significantly from Aerobic or Resistance. Waist circumference decreased 0.2 cm in control, 3.0 cm in Aerobic ($p=0.006$ versus control), 2.2 cm in Resistance ($p=0.048$ versus control), and 4.1 cm in Combined. In the prespecified subgroup with ≥70% adherence, %BF decreased 0.3% in controls, 1.2% in Aerobic ($p=0.045$ versus control), 1.6% in Resistance ($p=0.013$ versus control), 2.4% in Combined ($p= 0.036$ versus Aerobic) and waist circumference decreased 0.6 cm in controls, 3.7 cm in Aerobic, 4.5 cm in Resistance, 6.9 cm in Combined (significantly greater in Combined versus Aerobic).

CONCLUSIONS: Aerobic, resistance, and their combination reduced total body fat and waist circumference in obese adolescents. Combined training showed greater improvements compared to either exercise modality alone in more adherent participants.

Clinical Trial Registration # and Date: ClinicalTrials.Gov NCT00195858**,** September 12, 2005 (Funded by the Canadian Institutes of Health Research).

Keywords: Obesity, overweight, pediatric, adolescents, resistance exercise, aerobic exercise, clinical trial, intervention, body composition, cardiometabolic risk, magnetic resonance imaging.

INTRODUCTION

Childhood obesity[1-2] and physical inactivity[3] are serious public health concerns. Obesity is associated with adverse health outcomes in youth[4] and 80% of obese adolescents become obese adults.[5] Although exercise is recommended in obesity management, the optimal exercise prescription to reduce total body fat and its co-morbidities is not clear in obese adolescents.

We designed the Healthy Eating Aerobic and Resistance Training in Youth (HEARTY) trial to determine the effects of aerobic training, resistance training, combined aerobic and resistance training, or a non-exercising-control on percent body fat and cardiometabolic risk markers in previously inactive post-pubertal overweight and obese adolescents aged 14-18 years. The primary outcome was percent body fat measured by Magnetic Resonance Imaging (MRI). Secondary outcomes included total body fat, anthropometric indices of body fat distribution and risk markers for cardiovascular disease and diabetes.

METHODS

Design

HEARTY was a 26-week randomized controlled trial with a parallel group design. Details on the rationale, design and methods have been described previously.[6] This study was approved by the Research Ethics Boards at the Children's Hospital of Eastern Ontario and the Ottawa Hospital, Canada.

Participants

The study population consisted of post-pubertal (Tanner stage IV-V) adolescents aged 14-18 years with body mass index (BMI) $\geq 95^{th}$ percentile for age and sex (http://www.cdc.gov/growthcharts) and/or ≥85th percentile with an additional diabetes or cardiovascular disease risk factor. Participants were excluded if they habitually exercised more than twice weekly for over 20 minutes per session, had diabetes mellitus, or any illness or disability rendering the study exercise programs inadvisable or unfeasible. For participants taking medication likely to affect body composition (e.g. metformin, oral contraceptives, stimulants), the dose was required to have been stable over the previous two months and to remain unchanged throughout the trial.

Run-in

Participants entered a run-in period including supervised moderate-intensity exercise training four times per week for four weeks. They performed 15-30 minutes of aerobic exercise at 65% of their measured maximal heart rate and 1-3 sets of 15 repetitions for each of the 7 resistance exercises. Details of the exercise training program have been previously described.[6]

Randomization

To qualify for randomization, participants needed to have attended at least 13 of 16 prescribed exercise sessions (≥80% adherence) during run-in. The exercise specialist used a telephone-based central randomization program (IVRS, VBvoice v5.3, Pronexus,Ottawa, Canada) and informed participants of their group assignments, allowing the research coordinator to remain blinded. Participants (n=304) were randomized into 4 groups for 22 weeks: aerobic training (Aerobic, n=75), resistance training (Resistance, n=78), combined aerobic and resistance training (Combined, n=75), or non-exercising control (Control, n=76). Randomization was in permuted blocks, stratified by sex and degree of overweight (85th-94th percentile versus ≥95th percentile).

Intervention

All 4 groups received dietary counseling designed to promote healthy eating with a maximum daily energy deficit of 250 kcal. In addition to the dietary counseling, all three exercising groups were asked to attend the gym 4 times per week. Exercise training progressed gradually in duration and intensity. The aerobic training group exercised on treadmills, elliptical machines or bicycle ergometers, and heart rate monitors were used to adjust workloads to achieve target heart rates (Polar Electro Oy, Kempele, Finland). Participants gradually progressed in exercise duration (from 20 to 45 minutes per aerobic exercise session) and intensity (from 65 to 85% of maximum heart rate throughout the intervention. The resistance training group performed 7 different exercises on weight machines or by using free weights, progressing from 2 sets of 15 repetitions at moderate intensity to 3 sets of 8 repetitions at the maximum resistance that could be moved 8 times (8 RM). The combined aerobic and resistance training group did the full aerobic training program plus the resistance training program during each session.

Setting

The exercise intervention took place at six community-based exercise facilities in Ottawa/Gatineau, Canada. Exercise was supervised by personal trainers twice per week during the first month of the run-in period, once per week from randomization to 3-months and then once every two weeks from 3 months to 6 months. Personal trainers monitored attendance and exercise progression by reviewing sign-in sheets, electronic scanning of membership cards and completion of the participants' exercise logs. Intervention adherence was calculated as the total number of exercise sessions the participant attended divided by the total number of sessions prescribed.

Outcomes & Measurements

Body Composition

Body composition was assessed by MRI (General Electric, 1.5 tesla scanner, version signal 11 with echo speed gradients, Milwaukee, WI) at baseline and 6 months. The participants lay prone to acquire whole body cross-sectional images using established protocols by Ross.[7-8] The MRI images were analyzed using Slice-O-Matic software v. 4.3 (Tomovision, Magog, Canada).

Anthropometry, Background Physical Activity and Energy Intake

Weight (kg) and height (cm) were measured using a Health-O-Meter manual scale (Health O Meter, Continental Scale Corp., Bridgeview, ILL) and body-mass index (BMI) was calculated as weight in kilograms divided by the square of the height in meters. Waist circumference was measured at the midpoint between the lowest floating rib and the iliac crest using a retractable measuring tape (Seca GmBH & Co Kg, Hamburg, Germany). Hip circumference was measured at the widest point over the buttocks. Blood pressure was measured at baseline, 3 and 6 months as described previously.[6] Participants were asked to wear pedometers (Yamax DIGIWALKER SW-700, Yamax Corporation, Tokyo, Japan) and maintain step-count logs for 7 days at baseline and 6 months to assess background physical activity. Energy intake was assessed using 3-day food diaries and analyzed with food composition analysis software (The Food 324 Processor SQL 2006, ESHA Research, Salem, OR) at baseline, 3 and 6 months.

Cardiometabolic Risk Markers

Fasting insulin, fasting glucose, haemoglobin A1c (HbA1c) and lipids were measured under fasting conditions at baseline, 3 and 6 months as described previously.[6] A 75 g oral glucose tolerance test was performed at baseline and 6 months where 2-hour (post-load) glucose was also measured.

Adverse Events

Research staff reported all directly observed adverse events and all those spontaneously reported by the participants. Participants were also questioned about adverse events at each study visit.

Statistical Analysis

To assess the effects of exercise training modality on changes in percent body fat (primary outcome) over time, assuming a moderate effect size of 0.6 SD for the least powered planned comparison, we calculated a sample size of 248 participants (62 per group) completing the intervention to allow 80% power for each of 4 pre-specified comparisons (Aerobic versus Control, Resistance versus Control, Combined versus Aerobic and Combined versus Resistance) tested simultaneously (overall alpha=0.05). We randomized 304 participants to allow for 18–20% dropout similar to rates observed in previous exercise trials in obese youth[9] and in adults with type 2 diabetes.[10] We performed analyses on an intention-to-treat basis and included all randomly allocated participants (including those who later withdrew). For the primary analysis, we used linear mixed-effects modeling for repeated measures over time with percent body fat as the dependent variable and effects for time (baseline and 6 months), group [Aerobic, Resistance, Combined, Control], and time by group interaction, with age, and sex as covariates, and an unstructured covariance matrix. Within the mixed model, we calculated 95% confidence intervals and p-values for 4 prespecified intergroup contrasts, and for change in percent body fat within each group over time. We used the same procedure for other continuous outcome variables from the 3-month timepoint when available in addition to the baseline and 6-month timepoint. For all linear mixed-model analyses, we examined the distributions of residuals and used transformations to achieve normality when necessary. We also examined the effects of the exercise intervention in per-protocol analyses, restricted to participants with complete baseline and follow-up data with ≥70% adherence throughout the exercise intervention following the same procedures as in the intention-to-treat analyses. We used SAS, version #9.2 (SAS Institute, Cary, North Carolina), for all analyses.

RESULTS

Participant recruitment and screening began in March 2005 and recruitment closed at the end of April 2010. The final participant follow-up was completed in May 2011. Of the 358 participants who entered the run-in phase, 304 (84.9%) were randomized. Of the 54 who were not randomized, reasons for withdrawal included the time obligation, lack of interest or a move to a different town/city or a medical condition (Figure 1). Seven participants (1 from Aerobic, 3 from Resistance, 1 from Combined and 2 from Control) were excluded from MRI analyses because the images were technically inadequate.

Table 1 shows participants' baseline characteristics. There were no significant intergroup baseline differences. Most participants (282 out of 304 or 92.8%) were obese (BMI ≥ 95th percentile for age and sex).

Adherence

From baseline to 26 weeks, the median exercise training adherence was 62% (interquartile range, 36% to 81%) in Aerobic, 56% (interquartile range, 37% to 75%) in Resistance and 64% (interquartile range, 39% to 75%) in Combined with no significant differences between groups. Seventy five participants (25%) withdrew between randomization and 6 months: 18 (24%) from Aerobic, 21 (28%) from Resistance, 17 (23%) from Combined, and 19 (25%) from Control. Reasons for withdrawal are listed in Figure 1.

Adverse Events

Tables S1 and S2 in the Supplementary Appendix show the details of the adverse events reported during the trial. Two participants, both in Aerobic, withdrew because of adverse events unrelated to the exercise intervention: fractured hip from a fall at school (1 participant) and fractured forearm while playing football (1 participant). Overall, adverse events occurred in 49 of the 228 (21%) exercise group participants and 18 of the 76 (24%) Controls. Musculoskeletal injury or discomfort requiring modification of the exercise program or temporary restriction of physical activity occurred in 27 of the 228 (12%) exercise group participants and 2 of the 76 (3%) Controls. Adverse events that were definitely, probably or possibly related to the intervention occurred in 18 of the 228 (8%) exercise group participants and in 1 of the 76 (1%) Controls (during the run-in phase, prior to randomization). Almost all related adverse events involved musculoskeletal injury or discomfort. There were two reported medical adverse events that were possibly related to the intervention: post-exertional malaise (1 participant) and non-cardiac chest pain during exercise (1 participant).

Primary Outcome: Percent Body Fat

Body fat results are presented in Table 2. Data from seven participants (1 from Aerobic, 3 from Resistance, 1 from Combined and 2 from Control) were excluded due to technical deficiencies in MRI images. Percent body fat decreased in all exercising groups. Decreases in percent body fat were greater in Resistance compared to Control. In per-protocol analyses (≥70% adherence; ≥2.8 sessions/week) changes in percent body fat were significantly greater in the Aerobic and Resistance groups versus control, and larger decreases in percent body fat were observed in Combined versus Aerobic.

Secondary Outcomes: Anthropometry and Cardiometabolic Risk Markers

Table 3 presents effects of the exercise intervention on anthropometric indices. Reductions in waist circumference were greater in Aerobic and Resistance compared to Control. In per-protocol analyses, BMI decreased in Aerobic versus Control and the decreases were greater in Combined versus Aerobic and in Combined versus Resistance. Waist circumference decreased in Aerobic and Resistance versus Control, and significantly more in the Combined group compared to the Aerobic group.

Table S3 in the Supplementary Appendix shows results for cardiometabolic risk factors. Fasting insulin and triglycerides were log-transformed for analysis; geometric means are presented. There were no significant intergroup differences in fasting insulin, fasting or 2 hour-(post load) glucose, triglycerides, high density lipoprotein (HDL-C), low density lipoprotein (LDL-C) and total cholesterol, or hemoglobin A1c (HbA1c) between groups following the intervention. In per-protocol analyses, the only significant intergroup difference was that fasting insulin decreased more in the Resistance group than in Controls.

Energy Intake and Background Physical Activity

Within-group energy intake (3-day food logs) decreased in all groups to a similar extent. There were no significant between-group differences in energy intake or background physical activity (pedometer logs, excluding exercise sessions that were part of the intervention) in either intention-to-treat or per-protocol analyses. Data on background physical activity were limited as many participants did not wear pedometers or complete pedometer logs as instructed (Table 4).

DISCUSSION

The HEARTY trial was the first randomized controlled trial to compare the effects of aerobic training, resistance training and their combination on body composition and cardiometabolic risk factors in a large sample of obese adolescents. The primary findings were that modest but clinically significant reductions in percent body fat can be achieved through aerobic, resistance or combined exercise training in obese adolescents. Per-protocol analyses (including only participants with ≥70% adherence) showed that combined aerobic and resistance training produced greater decreases in percent body fat, waist circumference and BMI than aerobic training alone.

The modest decreases in percent body fat in the HEARTY trial were comparable to those observed by Lee et al.,[11] who examined the effects of thrice-weekly aerobic training or resistance training versus a non-exercising control group over a 3-month period. They showed decreases in the aerobic group (2.6%) and in the resistance group (2.5%) versus controls. Although the exercise prescriptions in Lee et al. and HEARTY were similar, the Lee study showed greater reductions in percent body fat in both exercising groups, possibly attributed to their higher exercise adherence rate (99%) and/or because their participants received some financial compensation.

Compared to controls, we found decreases in waist circumference in all three training groups. Per-protocol analyses showed greater waist circumference decreases in Combined versus Aerobic. Our results agree with previous smaller studies that showed decreases in abdominal fat through aerobic training,[11] resistance training[11] and combined aerobic and resistance circuit training[12-13] performed 2-3 times per week compared to non-exercising controls. Abdominal fat accumulation is associated with increased cardiometabolic risk.[14] Attenuating increases in abdominal fat during the adolescent years could confer important cardiometabolic protection since each additional year of abdominal obesity has been associated with a 4% greater risk of developing diabetes.[15]

The present study did not show changes in glucose or lipids following the 6-month exercise training program, possibly due to mostly-normal baseline values. Potential participants who had type 2 diabetes at baseline were excluded from our study, and the great majority (87%) of our study participants had normal baseline fasting and 2-hour postload glucose leaving little room for improvement in glucose measures. Our per-protocol analyses, however, showed that our adherent participants in the resistance training group had decreases in fasting insulin compared to controls, similarly to some previous studies in obese adolescents that showed improvements in insulin sensitivity.[11-13, 16] Two smaller randomized controlled studies by Lee[11] and Shaibi[16] showed that performing resistance exercise 2-3 times/week increased insulin sensitivity by 27% (3-hour hyperinsulinemic-euglycemic clamp) in black, white and mixed racial obese adolescent males and by 45% (frequently sampled intravenous glucose tolerance test) in obese Latino adolescent males respectively. Lee[11] found no changes in insulin sensitivity in the aerobic group. The ethnic background and sex of our HEARTY participants (72% Caucasian, 72% female) differed from previous research conducted with male Latino youth[12-13, 16] who are more likely to be insulin resistant than their Caucasian peers independent of body fat.[17] Although body fat distribution and metabolic risk factors differ according to race in adolescents[18] and severely insulin resistant obese youth have more adverse cardiometabolic risk markers than less insulin resistant obese adolescents,[19] our results suggest that resistance training alone could improve fasting insulin in a primarily Caucasian sample of obese adolescents.

We excluded obese adolescents with type 2 diabetes so our results do not necessarily apply to that population. Our results cannot necessarily be generalized to unsupervised exercise programs. The estimated monthly cost of our intervention averaged $188 Canadian/ participant/ month. The average gym membership cost was $28/month plus 1 personal training session/ week ($40/ training session) for the first 4 weeks. A completely adherent participant would receive 23 personal training sessions in the first 6 months. Costs would decrease over time, assuming the required frequency of personal trainer sessions would decrease.

The primary result of the HEARTY study was that aerobic training, resistance training and their combination decreased percent body fat in obese adolescents. In participants adhering to the exercise protocol, combined aerobic and resistance exercise training was more effective than either type of exercise alone in decreasing percent body fat, waist circumference and BMI in a large sample of obese adolescents exercising in community-based exercise facilities.

TABLE 1. Baseline participant characteristics.

	Total sample	Aerobic	Resistance	Combined	Control
N	304	75	78	75	76
Males, N (%)	91 (30)	22 (29)	23 (29)	22 (29)	24 (32)
Females, N (%)	213 (70)	53 (71)	55 (71)	53 (71)	52 (68)
Age, years	15.6 (1.4)	15.5 (1.4)	15.9 (1.5)	15.5 (1.3)	15.6 (1.3)
Ethnicity, N (%)					
Caucasian	219 (72)	54 (72)	55 (71)	47 (63)	63 (83)
Black	31 (10)	6 (8)	11 (14)	12 (16)	2 (3)
Mixed racial	14 (5)	5 (7)	2 (3)	3 (4)	4 (5)
Arabic	11(4)	4 (5)	1 (1)	4 (5)	2 (3)
Hispanic	9 (3)	4 (5)	2 (3)	3 (4)	0 (0)
Asian	8 (3)	0 (0)	4 (5)	2 (3)	2 (3)
Other	6 (2)	1 (1)	2 (3)	2 (3)	1 (1)
Native Canadian	4 (1)	0 (0)	0 (0)	2 (3)	2 (3)
Indonesian/Asian	2 (1)	1 (1)	1 (1)	0 (0)	0 (0)
Weight, kg	98.0 (16.9)	96.7 (15.1)	99.9 (17.4)	97.5 (16.3)	97.9 (18.8)
Height, cm	167.8 (7.4)	166.8 (7.0)	168.3 (7.5)	167.5 (7.6)	168.8 (7.7)
BMI ≥95th percentile, N (%)	282 (93)	69 (92)	71 (91)	71 (95)	71 (93)
Normal glucose tolerance, N (%)	263 (87)	62 (83)	66 (85)	67 (89)	68 (89)

Values are means (SD) unless otherwise stated.
Note: Percentages were rounded to the nearest 1%.

TABLE 2. Percent body fat at baseline and changes after 6 months.

		Mean (SE)		Mean (95% Confidence Interval)	
Variable	N	Baseline	6 months	Absolute change from baseline to 6 months	Adjusted change from baseline to 6 months
			INTENTION-TO-TREAT ANALYSIS (n= 297)		
Percent body fat (%)					
Aerobic	74	49.1 (0.6)	48.0 (0.7)	-1.1 (-1.7, -0.5)***	
Resistance	75	49.7 (0.6)	48.1 (0.7)	-1.6 (-2.3, -1.0)***	
Combined	74	50.2 (0.6)	48.8 (0.7)	-1.4 (-2.0, -0.8)***	
Control	74	48.6 (0.6)	48.3 (0.7)	-0.3 (-0.9, 0.3)	
Aerobic vs. control					-0.8 (-1.6, 0)
Resistance vs. control					-1.3 (-2.1, -0.5)**
Combined vs. aerobic					-0.3 (-1.2, 0.5)
Combined vs. resistance					0.2 (-0.7, 1.0)
Total body fat mass (kg)					
Aerobic	74	47.1 (1.3)	45.9 (1.4)	-1.2 (-2.4, 0)	
Resistance	75	48.0 (1.3)	46.7 (1.4)	-1.3 (-2.5, -0.1)*	
Combined	74	48.4 (1.3)	46.8 (1.4)	-1.7 (-2.9, -0.5)**	
Control	74	46.6 (1.3)	47.0 (1.4)	0.4 (-0.8, 1.6)	
Aerobic vs. control					-1.6 (-3.3, 0.1)
Resistance vs. control					-1.7 (-3.4, 0)
Combined vs. aerobic					-0.5 (-2.2, 1.2)
Combined vs. resistance					-0.4 (-2.1, 1.3)

PER-PROTOCOL ANALYSIS (n= 161)					
Percent body fat (%)					
Aerobic	35	48.8 (0.8)	47.5 (0.9)	-1.2 (-2.0, -0.5)**	
Resistance	23	49.4 (1.0)	47.8 (1.1)	-1.6 (-2.5, -0.8)***	
Combined	29	50.2 (0.9)	47.8 (1.0)	-2.4 (-3.2, -1.6)***	
Control	74	48.4 (0.6)	48.1 (0.6)	-0.3 (-0.9, 0.3)	
Aerobic vs. control					-0.9 (-1.9, 0)*
Resistance vs. control					-1.4 (-2.4, -0.3)*
Combined vs. aerobic					-1.2 (-2.2, -0.1)*
Combined vs. resistance					-0.7 (-1.9, 0.5)
Total body fat mass (kg)					
Aerobic	35	46.3 (1.8)	44.9 (2.0)	-1.5 (-3.0, 0.1)	
Resistance	23	49.9 (2.3)	49.2 (2.4)	-0.7 (-2.7, 1.2)	
Combined	29	48.0 (2.0)	45.0 (2.2)	-3.0 (-4.7, -1.3)***	
Control	74	46.6 (1.3)	47.0 (1.4)	0.4 (-0.8, 1.6)	
Aerobic vs. control					-1.9 (-3.8, 0.1)
Resistance vs. control					-1.1 (-3.4, 1.2)
Combined vs. aerobic					-1.5 (-3.9, 0.8)
Combined vs. resistance					-2.3 (-4.9, 0.3)

*p<0.05, **p<0.01, ***p<0.001.

Data from seven participants (1, 3, 1, 2 from the Aerobic, Resistance, Combined and Control groups respectively) were excluded from the intention-to-treat analysis, and two participants from the Control group were excluded from the per-protocol analysis in this table due to technically inadequate MRI images.

TABLE 3. Anthropometry at baseline and changes after 3 and 6 months.

		Mean (SE)			Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**3 months**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
INTENTION-TO-TREAT ANALYSIS (n=304)						
Total body weight (kg)						
Aerobic	75	97.1 (1.8)	96.9 (1.8)	97.0 (1.9)	-0.1 (-1.7, 1.5)	
Resistance	78	100.1 (1.7)	99.7 (1.8)	100.4 (1.9)	0.3 (-1.3, 1.9)	
Combined	75	97.8 (1.8)	97.3 (1.8)	97.0 (1.9)	-0.8 (-2.4, 0.7)	
Control	76	97.9 (1.8)	98.5 (1.8)	99.2 (1.9)	1.3 (-0.3, 3.0)	
Aerobic vs. control						-1.4 (-3.6, 0.8)
Resistance vs. control						-1.0 (-3.3, 1.2)
Combined vs. aerobic						-0.8 (-3.0, 1.4)
Combined vs. resistance						-1.1 (-3.3, 1.0)

Body mass index (kg/m^2)						
Aerobic	75	34.7 (0.5)	34.2 (0.5)	34.2 (0.6)	-0.6 (-1.1, -0.0)*	
Resistance	78	35.1 (0.5)	34.6 (0.5)	34.6 (0.6)	-0.5 (-1.1, 0)	
Combined	75	34.7 (0.5)	34.1 (0.5)	33.8 (0.6)	-0.9 (-1.4, -0.4)***	
Control	76	34.2 (0.5)	34.0 (0.5)	34.2 (0.6)	0.0 (-0.5, 0.6)	
Aerobic vs. control						-0.6 (-1.3, 0.1)
Resistance vs. control						-0.5 (-1.3, 0.2)
Combined vs. aerobic						-0.3 (-1.1, 0.4)
Combined vs. resistance						-0.4 (-1.1, 0.3)
Waist circumference (cm)						
Aerobic	75	96.6 (1.2)	93.4 (1.2)	93.6 (1.3)	-3.0 (-4.4, -1.6)***	
Resistance	78	98.9 (1.1)	96.5 (1.2)	96.7 (1.3)	-2.2 (-3.7, -0.8)**	
Combined	75	97.0 (1.2)	92.7 (1.2)	92.8 (1.3)	-4.1 (-5.5, -2.7)***	
Control	76	95.2 (1.1)	93.8 (1.2)	94.9 (1.3)	-0.2 (-1.7, 1.2)	
Aerobic vs. control						-2.8 (-4.7, -0.8)**
Resistance vs. control						-2.0 (-4.0, -0.0)*
Combined vs. aerobic						-1.1 (-3.0, 0.8)
Combined vs. resistance						-1.9 (-3.8, 0.1)

Hip circumference (cm)						
Aerobic	75	117.1 (1.1)	116 (1.1)	115.7 (1.2)	-1.3 (-2.5, -0.1)*	
Resistance	78	118.4 (1.0)	117.1 (1.0)	117.2 (1.2)	-1.2 (-2.5, 0)*	
Combined	75	117.6 (1.1)	116.2 (1.1)	115.8 (1.1)	-1.7 (-2.9, -0.6)**	
Control	76	117 (1.1)	116.7 (1.1)	117.6 (1.2)	0.6 (-0.6, 1.8)	
Aerobic vs. control						-1.9 (-3.6, -0.2)*
Resistance vs. control						-1.8 (-3.5, -0.1)*
Combined vs. aerobic						-0.4 (-2.0, 1.3)
Combined vs. resistance						-0.5 (-2.1, 1.2)
Waist-to-hip ratio						
Aerobic	75	0.82 (0.01)	0.81 (0.01)	0.81 (0.01)	-0.01 (-0.02, 0)**	
Resistance	78	0.84 (0.01)	0.82 (0.01)	0.82 (0.01)	-0.01 (-0.02, 0)*	
Combined	75	0.82 (0.01)	0.80 (0.01)	0.80 (0.01)	-0.02 (-0.03, -0.01)***	
Control	76	0.81 (0.01)	0.80 (0.01)	0.81 (0.01)	-0.00 (-0.01, 0.01)	
Aerobic vs. control						-0.01 (-0.02, 0)
Resistance vs. control						-0.01 (-0.02, 0)
Combined vs. aerobic						-0.01 (-0.02, 0)
Combined vs. resistance						-0.01 (-0.02, 0)

Systolic blood pressure (mmHg)						
Aerobic	75	115 (1)	111 (1)	111 (1)	-5 (-7, -2)***	
Resistance	78	116 (1)	111 (1)	112 (1)	-4 (-6, -1)**	
Combined	75	111 (1)	107 (1)	110 (1)	-1 (-3, 2)	
Control	76	114 (1)	109 (1)	110 (1)	-4 (-6, -1)**	
Aerobic vs. control						-1 (-5, 2)
Resistance vs. control						0 (-4, 4)
Combined vs. aerobic						4 (0, 7)*
Combined vs. resistance						3 (-1, 6)
Diastolic blood pressure (mmHg)						
Aerobic	75	75 (1)	75 (1)	72 (1)	-3 (-5, -1)**	
Resistance	78	76 (1)	75 (1)	74 (1)	-2 (-5, 0)*	
Combined	75	75 (1)	73 (1)	73 (1)	-2 (-4, 0)	
Control	76	74 (1)	73 (1)	73 (1)	-1 (-3,1)	
Aerobic vs. control						-2 (-5, 1)
Resistance vs. control						-1 (-4, 2)
Combined vs. aerobic						1 (-2, 4)
Combined vs. resistance						0 (-3, 3)

PER-PROTOCOL ANALYSIS (n= 163)						
Total body weight (kg)						
Aerobic	35	97.1 (2.7)	96.5 (2.7)	96.0 (2.8)	-1.2 (-3.3, 0.9)	
Resistance	23	104.1 (3.3)	103.1 (3.3)	103.7 (3.4)	-0.4 (-3.0, 2.1)	
Combined	29	97.5 (3.0)	95.3 (3.0)	94.2 (3.0)	-3.2 (-5.5, -1.0)**	
Control	76	98.6 (1.8)	99.1 (1.8)	99.7 (1.9)	1.1 (-0.5, 2.7)	
Aerobic vs. control						-2.3 (-4.8, 0.3)
Resistance vs. control						-1.5 (-4.5, 1.4)
Combined vs. aerobic						-2.1 (-5.1, 0.9)
Combined vs. resistance						-2.8 (-6.2, 0.6)
Body Mass Index (kg/m^2)						
Aerobic	35	34.5 (0.7)	33.7 (0.8)	33.6 (0.8)	-1.0 (-1.6, -0.3)**	
Resistance	23	35.9 (0.9)	35.3 (0.9)	35.1 (1.0)	-0.8 (-1.6, 0.1)	
Combined	29	34.9 (0.8)	33.6 (0.8)	32.9 (0.9)	-2.0 (-2.7, -1.2)***	
Control	76	34.3 (0.5)	34.0 (0.5)	34.2 (0.6)	-0.1 (-0.6, 0.5)	
Aerobic vs. control						-0.9 (-1.7, -0.1)*
Resistance vs. control						-0.7 (-1.7, 0.2)
Combined vs. aerobic						-1.0 (-2.0, 0)*
Combined vs. resistance						-1.2 (-2.3, -0.1)*

Waist circumference (cm)						
Aerobic	35	96.1 (1.6)	92.6 (1.7)	92.4 (1.8)	-3.7 (-5.4, -2.0)***	
Resistance	23	103.2 (2)	99.8 (2.1)	98.7 (2.2)	-4.5 (-6.7, -2.4)***	
Combined	29	97.3 (1.8)	91.4 (1.8)	90.4 (1.9)	-6.9 (-8.7, -5.0)***	
Control	76	95.7 (1.1)	94.2 (1.2)	95.1 (1.2)	-0.6 (-1.9, 0.8)	
Aerobic vs. control						-3.1 (-5.2, -1.0)**
Resistance vs. control						-4.0 (-6.4, -1.5)**
Combined vs. aerobic						-3.1 (-5.6, -0.7)*
Combined vs. resistance						-2.3 (-5.1, 0.5)
Hip circumference (cm)						
Aerobic	35	116.9 (1.6)	115.9 (1.6)	115.4 (1.7)	-1.5 (-3.0, 0)*	
Resistance	23	120.8 (2.0)	118.6 (1.9)	118.9 (2.1)	-1.9 (-3.7, -0.1)*	
Combined	29	118.1 (1.8)	115.6 (1.7)	115.1 (1.9)	-3.0 (-4.6, -1.3)***	
Control	76	117.1 (1.1)	116.8 (1.1)	117.6 (1.2)	0.5 (-0.6, 1.7)	
Aerobic vs. control						-2.0 (-3.8, -0.2)*
Resistance vs. control						-2.4 (-4.5, -0.4)*
Combined vs. aerobic						-1.5 (-3.6, 0.6)
Combined vs. resistance						-1.0 (-3.4, 1.3)

Waist-to-hip ratio						
Aerobic	35	0.82 (0.01)	0.80 (0.01)	0.80 (0.01)	-0.02 (-0.03, -0.01)**	
Resistance	23	0.85 (0.01)	0.84 (0.01)	0.83 (0.01)	-0.03 (-0.04, -0.01)***	
Combined	29	0.82 (0.01)	0.79 (0.01)	0.78 (0.01)	-0.04 (-0.05, -0.03)***	
Control	76	0.82 (0.01)	0.81 (0.01)	0.81 (0.01)	-0.01 (-0.01, 0.)	
Aerobic vs. control						-0.01 (-0.03, 0)
Resistance vs. control						-0.02 (-0.04, 0)*
Combined vs. aerobic						-0.02 (-0.04, 0)*
Combined vs. resistance						-0.01 (-0.03, 0.01)
Systolic blood pressure (mmHg)						
Aerobic	35	116 (2)	109 (1)	109 (1)	-7 (-10, -4)***	
Resistance	23	120 (2)	113 (2)	114 (2)	-5 (-9, -1.)*	
Combined	29	111 (2)	106 (2)	110 (2)	-1 (-5, 3)	
Control	76	114 (1)	110 (1)	111 (1)	-4 (-6, -1)**	
Aerobic vs. control						-3 (-8, 1)
Resistance vs. control						-2 (-6, 3)
Combined vs. aerobic						6 (1, 11)*
Combined vs. resistance						4 (-1, 10)

Diastolic blood pressure (mmHg)						
Aerobic	35	75 (1)	74 (1)	71 (1)	-4 (-7, -1)*	
Resistance	23	78 (2)	75 (1)	75 (2)	-3 (-6, 1)	
Combined	29	75 (1)	73 (1)	72 (1)	-3 (-6, 1)	
Control	76	74 (1)	73 (1)	73 (1)	-1 (-4, 1)	
Aerobic vs. control						-2 (-6, 1)
Resistance vs. control						-1 (-6, 3)
Combined vs. aerobic						1 (-3, 5)
Combined vs. resistance						0 (-5, 5)

*p<0.05, **p<0.01, ***p<0.001.

Table 4. Changes in energy intake (3-day food diaries) and background physical activity (7-day pedometer logs) in the aerobic, resistance, combined and control groups.

		Mean (SE)			Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**3 months**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
			INTENTION-TO-TREAT ANALYSIS			
Total energy intake (kilocalories/ day)						
Aerobic	75	2121 (72)	1920 (69)	1829 (67)	-292 (-463, -121)***	
Resistance	78	2315 (71)	1909 (69)	1938 (68)	-377 (-547, -207)***	
Combined	74	2199 (73)	1980 (67)	1874 (63)	-325 (-491, -159)***	
Control	76	2134 (72)	1896 (72)	1873 (66)	-261 (-429, -93)**	
Aerobic vs. control						-32 (-270, 207)
Resistance vs. control						-116 (-355, 123)
Combined vs. aerobic						-33 (-270, 205)
Combined vs. resistance						52 (-185, 289)

Total step counts (steps/day, excluding gym sessions)						
Aerobic	38	7184 (613)	-	7487 (1076)	303 (-2039, 2644)	
Resistance	53	8288 (519)	-	10109 (1384)	1821 (-1097, 4739)	
Combined	38	8210 (614)	-	9169 (1383)	959 (-1975, 3893)	
Control	36	7565 (634)	-	9789 (1539)	2224 (-1122, 5569)	
Aerobic vs. control						-1921 (-6003, 2161)
Resistance vs. control						-403 (-4851, 4045)
Combined vs. aerobic						657 (-3096, 4410)
Combined vs. resistance						-862 (-4996, 3272)

PER-PROTOCOL ANALYSIS						
Total energy intake (kilocalories/ day)						
Aerobic	35	2111 (110)	1924 (98)	1855 (80)	-256 (-486, -26)*	
Resistance	23	2498 (136)	2076 (120)	2121 (98)	-377 (-659, -94)**	
Combined	29	2143 (122)	1974 (106)	1894 (87)	-249 (-500, 3)	
Control	76	2148 (75)	1907 (77)	1879 (64)	-269 (-439, -99)**	
Aerobic vs. control						13 (-272, 298)
Resistance vs. control						-108 (-436, 221)
Combined vs. aerobic						7 (-332, 346)
Combined vs. resistance						128 (-248, 504)

Total step counts (steps/day, excluding gym sessions)						
Aerobic	21	6736 (775)	-	6106 (1161)	-630 (-3096, 1837)	
Resistance	19	7774 (817)	-	9455 (1444)	1681 (-1348, 4710)	
Combined	15	8233 (918)	-	9985 (1616)	1752 (-1623, 5127)	
Control	36	7646 (590)	-	10033 (1521)	2387 (-886, 5660)	
Aerobic vs. control						-3017 (-7101, 1067)
Resistance vs. control						-706 (-5168, 3755)
Combined vs. aerobic						2382 (-1798, 6561)
Combined vs. resistance						71 (-4462, 4604)

*p<0.05, **p<0.01, ***p<0.001.

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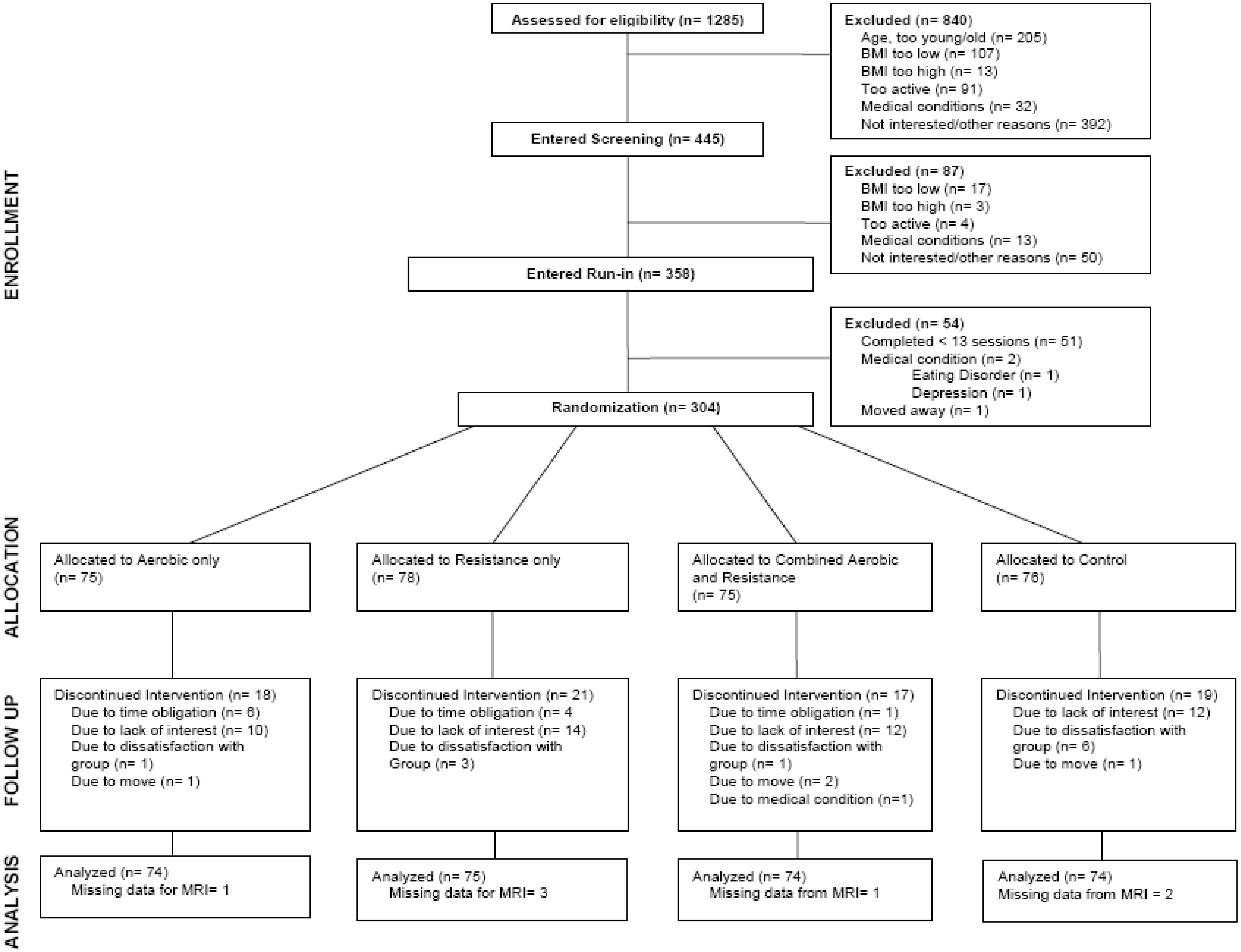
FIGURE LEGEND

FIGURE 1. HEARTY trial flow diagram


ENROLLMENT
Assessed for eligibility (n= 1285)
Excluded (n= 840)
Age, too young/old (n= 205)
BMI too low (n= 107)
BMI too high (n= 13)
Too active (n= 91)
Medical conditions (n= 32)
Not interested/other reasons (n= 392)
Entered Screening (n= 445)
Excluded (n= 87)
BMI too low (n= 17)
BMI too high (n= 3)
Too active (n= 4)
Medical conditions (n= 13)
Not interested/other reasons (n= 50)
Entered Run-in (n= 358)
Excluded (n= 54)
Completed < 13 sessions (n= 51)
Medical condition (n= 2)
Eating Disorder (n= 1)
Depression (n= 1)
Moved away (n= 1)
Randomization (n= 304)
ALLOCATION
Allocated to Aerobic only (n= 75)
Allocated to Resistance only (n= 78)
Allocated to Combined Aerobic and Resistance (n= 75)
Allocated to Control (n= 76)
FOLLOW UP
Discontinued Intervention (n= 18)
Due to time obligation (n= 6)
Due to lack of interest (n= 10)
Due to dissatisfaction with group (n= 1)
Due to move (n= 1)
Discontinued Intervention (n= 21)
Due to time obligation (n= 4
Due to lack of interest (n= 14)
Due to dissatisfaction with Group (n= 3)
Discontinued Intervention (n= 17)
Due to time obligation (n= 1)
Due to lack of interest (n= 12)
Due to dissatisfaction with group (n= 1)
Due to move (n= 2)
Due to medical condition (n=1)
Discontinued Intervention (n= 19)
Due to lack of interest (n= 12)
Due to dissatisfaction with group (n= 6)
Due to move (n= 1)
ANALYSIS
Analyzed (n= 74)
Missing data for MRI= 1
Analyzed (n= 75)
Missing data for MRI= 3
Analyzed (n= 74)
Missing data from MRI= 1
Analyzed (n= 74)
Missing data from MRI = 2

Online Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about the HEARTY trial results.

Supplement to: Effects of Aerobic and Resistance Exercise Training on Percent Body Fat and Cardiometabolic Risk Markers in Obese Adolescents: the HEARTY trial.

Table of Contents for Appendix

List of investigators:
Ronald J. Sigal, Angela S. Alberga, Gary S. Goldfield, Denis Prud'homme, Stasia Hadjiyannakis, Réjeanne Gougeon, Penny Phillips, Heather Tulloch, Janine Malcolm, Steve Doucette George Wells, Jinhui Ma, and Glen P. Kenny.

TABLE S1. Overall adverse events by study group*.

Adverse Events	**Combined Training Group (n = 75)**	**Aerobic Training Group (n = 75)**	**Resistance Training Group (n = 78)**	**Control Group† (n = 76)**
Serious adverse events & Hospitalizations	0 (0)	0 (0)	0 (0)	0 (0)
Any injury or musculoskeletal discomfort	17 (23)	12 (16)	15 (19)	10 (13)
Injury requiring modification of exercise program or restriction of activity	9 (12)	8 (11)	10 (13)	2 (3)
Withdrawal for medical reasons	0 (0)	2 (3)	0 (0)	0 (0)
All participants with Adverse Events	19 (25)	14 (19)	16 (21)	18 (24)
Type of Adverse Event				
Upper body (neck, shoulders, upper back, arms)	7 (9)	3 (4)	4 (5)	6 (8)
Lower body (lower back, hips, knees, ankle, feet)	8 (11)	9 (12)	10 13)	4 (5)
Musculoskeletal injury due to accident while exercising (dropping weight)	2 (3)	0 (0)	1 (1)	0 (0)
Anxiety or depression	0 (0)	1 (1)	0 (0)	3 (4)
Headache	0 (0)	0 (0)	0 (0)	1 (1)

Fainting	0 (0)	0 (0)	0 (0)	1 (1)
Respiratory infection	0 (0)	0 (0)	1 (1)	1 (1)
Other[¥]	2 (3)	1 (1)	0 (0)	2 (3)

*Data are the number (percentage) of participants. Percentages are rounded to the nearest 1%.

†injuries in the control group related to intervention occurred during run-in (prior to randomization).

¥ Includes 1 case each of post-exertional malaise, chest pain, kidney infection, ovarian cyst, accidental drug overdose.

TABLE S2. Adverse events by study group related and unrelated to participation in the HEARTY trial.

Adverse Events [n (percent)]	**Combined Training Group (n = 75)**		**Aerobic Training Group (n = 75)**		**Resistance Training Group (n = 78)**		**Control Group† (n = 76)**	
Relationship to exercise intervention	**related**	**unrelated**	**related**	**unrelated**	**related**	**unrelated**	**related**	**unrelated**
Serious adverse events & Hospitalizations	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Any injury or musculoskeletal discomfort	7 (9)	10 (13)	3 (4)	9 (12)	6 (8)	9 (12)	1 (1)	9 (12)
Upper body injury (neck, shoulders, upper back, arms)	3 (4)	4 (5)	0 (0)	3 (4)	1 (1)	3 (4)	1 (1)	5 (7)
Lower body injury (lower back, hips, knees, ankle, feet)	2 (3)	6 (8)	3 (4)	6 (8)	4 (5)	6 (8)	0 (0)	4 (5)

Musculoskeletal injury due to accident while exercising (dropping weight)	2 (3)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)
Injury required modification of exercise program or restriction of activity	3 (4)	6 (8)	1 (1)	7 (9)	3 (4)	7 (9)	1 (1)	1 (1)
All participants with Medical AEs	2 (3)	0 (0)	0 (0)	2 (3)	0 (0)	1 (1)	0 (0)	8 (11)
Mental Health (anxiety, depression)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	3 (4)
Neurological (headache, fainting)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (3)
Respiratory (cold/flu, pneumonia)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)
Other	2 (3)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	2 (3)
Withdrawal for medical reasons	0 (0)	0 (0)	0 (0)	2[Z] (3)	0 (0)	0 (0)	0 (0)	0 (0)

*Data are the number (percentage) of participants. Percentages are rounded to the nearest 1%.

†Injuries in the control group related to intervention occurred during run-in (prior to randomization).

¥ Includes 1 case each of post-exertional malaise, chest pain, kidney infection, ovarian cyst, accidental drug overdose.

[Z] Fractured hip from a fall at school (1 participant) and fractured forearm while playing football (1 participant).

TABLE S3. Cardiometabolic risk markers at baseline and changes after 3 and 6 months.

		Mean (SE)			Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**3 months**	**6 months**	**Absolute Change from Baseline to 6 months**	**Adjusted Change from Baseline to 6 months**
INTENTION-TO-TREAT ANALYSIS						
Fasting glucose (mmol/L)						
Aerobic	75	5.03 (0.05)	5.00 (0.05)	5.04 (0.06)	0.01 (-0.10, 0.13)	
Resistance	77	4.96 (0.05)	5.01 (0.05)	4.96 (0.06)	0.0 (-0.12, 0.12)	
Combined	75	4.91 (0.05)	4.92 (0.05)	4.85 (0.06)	-0.05 (-0.17, 0.06)	
Control	76	5.05 (0.05)	5.01 (0.05)	4.95 (0.06)	-0.10 (-0.22, 0.01)	
Aerobic vs. control						0.12 (-0.05, 0.28)
Resistance vs. control						0.10 (-0.06, 0.27)
Combined vs. aerobic						-0.07 (-0.23, 0.09)
Combined vs. resistance						-0.05 (-0.22, 0.11)

2 hour- (post-load) glucose (mmol/L)						
Aerobic	75	5.73 (0.14)	-	5.54 (0.17)	-0.19 (-0.56, 0.18)	
Resistance	78	6.02 (0.13)	-	6.04 (0.18)	0.02 (-0.36, 0.39)	
Combined	75	5.70 (0.14)	-	5.55 (0.17)	-0.15 (-0.51, 0.20)	
Control	74	5.79 (0.14)	-	5.67 (0.17)	-0.11 (-0.48, 0.25)	
Aerobic vs. control						-0.08 (-0.59, 0.43)
Resistance vs. control						0.13 (-0.39, 0.65)
Combined vs. aerobic						0.04 (-0.47, 0.55)
Combined vs. resistance						-0.17 (-0.69, 0.35)
Fasting insulin (pmol/L)†						
Aerobic	73	85.0 (5.3)	95.7 (6.7)	98.2 (7.4)	13.2 (0.4, 28.0)*	
Resistance	76	101.0 (6.1)	94.2 (6.5)	95.2 (7.4)	-5.9 (-18.7, 9.0)	
Combined	75	84.8 (5.2)	87.8 (6.0)	91.2 (6.8)	6.4 (-5.2, 19.8)	
Control	73	89.8 (5.6)	86.3 (6.2)	88.3 (6.7)	-1.5 (-13.1, 11.8)	
Aerobic vs. control						17.5 (-3.4, 43.1)
Resistance vs. control						-4.2 (-21.6, 17.0)
Combined vs. aerobic						-6.9 (-23.3, 13.0)
Combined vs. resistance						14.2 (-6.2, 39.2)

HbA1c (%)						
Aerobic	75	5.16 (0.03)	-	5.15 (0.03)	-0.01 (-0.08, 0.06)	
Resistance	77	5.20 (0.03)	-	5.16 (0.03)	-0.03 (-0.1, 0.03)	
Combined	74	5.18 (0.03)	-	5.16 (0.03)	-0.02 (-0.08, 0.05)	
Control	76	5.17 (0.03)	-	5.15 (0.03)	-0.02 (-0.09, 0.04)	
Aerobic vs. control						0.01 (-0.08, 0.10)
Resistance vs. control						-0.01 (-0.11, 0.08)
Combined vs. aerobic						-0.01 (-0.1, 0.09)
Combined vs. resistance						0.02 (-0.08, 0.11)
Total cholesterol (mmol/L)						
Aerobic	75	4.19 (0.09)	4.10 (0.10)	4.12 (0.10)	-0.08 (-0.22, 0.07)	
Resistance	78	4.27 (0.09)	4.20 (0.09)	4.13 (0.10)	-0.14 (-0.29, 0.01)	
Combined	75	4.22 (0.09)	4.12 (0.10)	4.03 (0.10)	-0.2 (-0.34, -0.05)**	
Control	76	4.39 (0.09)	4.40 (0.10)	4.40 (0.10)	0.01 (-0.14, 0.15)	
Aerobic vs. control						-0.08 (-0.29, 0.12)
Resistance vs. control						-0.14 (-0.35, 0.06)
Combined vs. aerobic						-0.12 (-0.32, 0.08)
Combined vs. resistance						-0.06 (-0.27, 0.14)

LDL-C (mmol/L)						
Aerobic	75	2.57 (0.08)	2.44 (0.08)	2.46 (0.09)	-0.11 (-0.24, 0.02)	
Resistance	78	2.58 (0.08)	2.54 (0.08)	2.43 (0.09)	-0.15 (-0.28, -0.01)*	
Combined	75	2.59 (0.08)	2.48 (0.08)	2.38 (0.09)	-0.21 (-0.34, -0.08)**	
Control	75	2.65 (0.08)	2.68 (0.09)	2.62 (0.09)	-0.03 (-0.16, 0.10)	
Aerobic vs. control						-0.08 (-0.26, 0.11)
Resistance vs. control						-0.12 (-0.3, 0.07)
Combined vs. aerobic						-0.1 (-0.28, 0.08)
Combined vs. resistance						-0.06 (-0.24, 0.13)
HDL-C (mmol/L)						
Aerobic	75	1.08 (0.03)	1.09 (0.03)	1.08 (0.03)	0.01 (-0.04, 0.05)	
Resistance	78	1.11 (0.03)	1.12 (0.03)	1.14 (0.03)	0.02 (-0.02, 0.07)	
Combined	75	1.10 (0.03)	1.09 (0.03)	1.13 (0.03)	0.03 (-0.01, 0.08)	
Control	76	1.12 (0.03)	1.15 (0.03)	1.14 (0.03)	0.02 (-0.03, 0.06)	
Aerobic vs. control						-0.01 (-0.07, 0.05)
Resistance vs. control						0.01 (-0.06, 0.07)
Combined vs. aerobic						0.03 (-0.03, 0.09)
Combined vs. resistance						0.01 (-0.05, 0.07)

Triglycerides (mmol/L)†						
Aerobic	75	1.09 (0.06)	1.08 (0.07)	1.12 (0.07)	0.03 (-0.08, 0.15)	
Resistance	78	1.16 (0.06)	1.05 (0.06)	1.14 (0.07)	-0.02 (-0.14, 0.11)	
Combined	75	1.04 (0.06)	1.07 (0.07)	1.01 (0.06)	-0.03 (-0.13, 0.09)	
Control	76	1.21 (0.07)	1.14 (0.07)	1.28 (0.08)	0.07 (-0.05, 0.22)	
Aerobic vs. control						-3.33 (-16.58, 12.03)
Resistance vs. control						-7.33 (-20.18, 7.59)
Combined vs. aerobic						-4.93 (-17.85, 10.02)
Combined vs. resistance						-0.82 (-14.46, 14.99)

PER-PROTOCOL ANALYSIS						
Fasting glucose (mmol/L)						
Aerobic	35	4.97 (0.07)	4.98 (0.06)	5.00 (0.07)	0.02 (-0.13, 0.18)	
Resistance	22	5.03 (0.09)	4.96 (0.07)	4.95 (0.09)	-0.07 (-0.27, 0.12)	
Combined	29	4.92 (0.08)	4.91 (0.06)	4.94 (0.08)	0.03 (-0.14, 0.20)	
Control	76	5.05 (0.05)	5.02 (0.04)	4.96 (0.06)	-0.09 (-0.21, 0.03)	
Aerobic vs. control						0.12 (-0.08, 0.31)
Resistance vs. control						0.02 (-0.21, 0.24)
Combined vs. aerobic						0 (-0.23, 0.23)
Combined vs. resistance						0.10 (-0.16, 0.36)

2 hour- (post-load) glucose (mmol/L)						
Aerobic	35	5.82 (0.19)	-	5.45 (0.20)	-0.36 (-0.77, 0.05)	
Resistance	23	6.20 (0.24)	-	5.75 (0.24)	-0.45 (-0.96, 0.06)	
Combined	29	5.51 (0.21)	-	5.03 (0.21)	-0.49 (-0.93, -0.04)*	
Control	74	5.80 (0.13)	-	5.68 (0.15)	-0.12 (-0.44, 0.20)	
Aerobic vs. control						-0.24 (-0.75, 0.27)
Resistance vs. control						-0.33 (-0.92, 0.26)
Combined vs. aerobic						-0.12 (-0.73, 0.48)
Combined vs. resistance						-0.04 (-0.71, 0.63)
Fasting insulin (pmol/L)†						
Aerobic	34	78.3 (7.2)	79.1 (7.1)	87.0 (8.6)	8.8 (-6.2, 26.9)	
Resistance	23	135.3 (15.1)	91.3 (10.0)	96.4 (12.0)	-38.8 (-59.0, -13.2)**	
Combined	29	81.1 (8.1)	72.6 (7.0)	78.6 (8.5)	-2.5 (-17.1, 15.4)	
Control	73	91.4 (5.7)	87.7 (5.8)	89.3 (6.7)	-2.0 (-14.2, 12.0)	
Aerobic vs. control						13.8 (-10.0, 43.9)
Resistance vs. control						-27.1 (-44.6, -4.1)*
Combined vs. aerobic						-12.9 (-33.8, 14.7)
Combined vs. resistance						36.0 (-0.2, 85.2)

HbA1c (%)						
Aerobic	35	5.20 (0.05)	-	5.17 (0.04)	-0.04 (-0.12, 0.05)	
Resistance	22	5.23 (0.06)	-	5.12 (0.05)	-0.11 (-0.22, 0)	
Combined	29	5.13 (0.05)	-	5.12 (0.05)	-0.01 (-0.11, 0.08)	
Control	76	5.17 (0.03)	-	5.15 (0.03)	-0.02 (-0.09, 0.04)	
Aerobic vs. control						-0.02 (-0.12, 0.09)
Resistance vs. control						-0.09 (-0.21, 0.04)
Combined vs. aerobic						0.03 (-0.1, 0.15)
Combined vs. resistance						0.1 (-0.05, 0.24)
Total cholesterol (mmol/L)						
Aerobic	35	4.15 (0.14)	4.00 (0.14)	4.06 (0.14)	-0.09 (-0.28, 0.10)	
Resistance	23	4.29 (0.18)	4.29 (0.18)	4.12 (0.17)	-0.18 (-0.41, 0.06)	
Combined	29	4.31 (0.16)	4.06 (0.16)	4.07 (0.15)	-0.24 (-0.45, -0.03)*	
Control	76	4.40 (0.10)	4.40 (0.10)	4.39 (0.10)	-0.01 (-0.16, 0.14)	
Aerobic vs. control						-0.08 (-0.31, 0.16)
Resistance vs. control						-0.17 (-0.44, 0.10)
Combined vs. aerobic						-0.15 (-0.43, 0.12)
Combined vs. resistance						-0.06 (-0.37, 0.24)

LDL-C (mmol/L)						
Aerobic	35	2.53 (0.13)	2.38 (0.13)	2.46 (0.13)	-0.08 (-0.25, 0.09)	
Resistance	23	2.59 (0.15)	2.59 (0.16)	2.42 (0.15)	-0.17 (-0.38, 0.04)	
Combined	29	2.57 (0.14)	2.38 (0.14)	2.33 (0.14)	-0.24 (-0.43, -0.05)*	
Control	75	2.66 (0.09)	2.68 (0.09)	2.61 (0.09)	-0.05 (-0.18, 0.09)	
Aerobic vs. control						-0.03 (-0.24, 0.18)
Resistance vs. control						-0.13 (-0.37, 0.12)
Combined vs. aerobic						-0.16 (-0.41, 0.09)
Combined vs. resistance						-0.07 (-0.34, 0.21)
HDL-C (mmol/L)						
Aerobic	35	1.09 (0.05)	1.09 (0.05)	1.08 (0.05)	-0.02 (-0.08, 0.04)	
Resistance	23	1.07 (0.06)	1.10 (0.06)	1.11 (0.06)	0.04 (-0.03, 0.11)	
Combined	29	1.18 (0.05)	1.16 (0.05)	1.23 (0.05)	0.04 (-0.02, 0.11)	
Control	76	1.12 (0.03)	1.14 (0.03)	1.13 (0.04)	0.01 (-0.03, 0.06)	
Aerobic vs. control						-0.03 (-0.10, 0.04)
Resistance vs. control						0.03 (-0.06, 0.11)
Combined vs. aerobic						0.06 (-0.02, 0.14)
Combined vs. resistance						0 (-0.09, 0.10)

Triglycerides (mmol/L)†						
Aerobic	35	1.05 (0.08)	0.97 (0.09)	1.06 (0.08)	0.01 (-0.13, 0.18)	
Resistance	23	1.28 (0.13)	1.16 (0.13)	1.17 (0.11)	-0.12 (-0.31, 0.11)	
Combined	29	1.11 (0.10)	1.02 (0.10)	1.01 (0.09)	-0.10, -0.24)	
Control	76	1.22 (0.07)	1.15 (0.08)	1.29 (0.08)	0.07 (-0.06, 0.22)	
Aerobic vs. control						-4.68 (-20.24, 13.91)
Resistance vs. control						-14.24 (-30.30, 5.53)
Combined vs. aerobic						-9.62 (-26.78, 11.57)
Combined vs. resistance						0.45 (-20.66, 27.18)

*p<0.05, **p<0.01, ***p<0.001.
†Values were log-transformed for analysis; geometric means are presented.
Abbreviations: HbA1c= Hemoglobin A1c, HDL-C= High density lipoprotein cholesterol, LDL= Low density lipoprotein cholesterol.
Note: We did not conduct an Oral Glucose Tolerance Test at 3 months to assess 2 hour- (post load) glucose nor did we measure HbA1c at 3 months. To convert the values for triglycerides to mg/dL, divide by 0.01129. To convert the values for cholesterol to mg/dL, divide by 0.02586. To convert the values for glucose to mg/dL, divide by 0.05551.

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MANUSCRIPT 6: Effects of aerobic training, resistance training or both on abdominal fat distribution, apolipoproteins and high-sensitivity C-reactive protein in obese adolescents: the HEARTY trial

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Statement of contributions of collaborators:

A.S. Alberga assisted with participant recruitment, screening, informed consent visits, study coordination, physical training and was responsible for the Magnetic Resonance Imaging body composition and abdominal fat analysis, bibliographic search, article screening, and drafted and edited the manuscript.

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Effects of aerobic training, resistance training or both on abdominal fat distribution, apolipoproteins and high-sensitivity C-reactive protein in obese adolescents: the HEARTY trial

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Running title: Exercise, abdominal fat and CVD risk factors in obese youth

ABSTRACT

Objective: To investigate the effects of aerobic training, resistance training, or both on abdominal subcutaneous fat (SAT) (deep and superficial), visceral fat (VAT), and Apolipoproteins A1, B (ApoA1, ApoB) ApoB/ApoA1 ratio and high-sensitivity C-reactive protein (HSCRP) in post-pubertal overweight and obese adolescents. **Design:** Randomized controlled trial. **Participants:** After a 4-week supervised moderate intensity exercise run-in period, 304 overweight (body mass index (BMI) ≥85th percentile for age and sex + diabetes risk factor) and obese (≥95th BMI percentile) adolescents aged 14-18 years old were randomized to 1 of 4 groups for 22 weeks (5 months): aerobic training, resistance training, combined training, or a non-exercising control. **Methods:** All participants received dietary counseling designed to promote healthy eating with a maximum daily energy deficit of 250 kcal. Abdominal fat (SAT and VAT) at the level of the 4th and 5th lumbar vertebrae was measured by Magnetic Resonance Imaging and ApoA-1, ApoB and HSCRP were measured after a 12-hr fast using standard methods at baseline and after 6 months. **Results:** Decreases in subcutaneous fat at L4-L5 were -16.2cm^2 in Aerobic (p=0.043 versus control), -22.7cm^2 in Resistance (p=0.009 versus control) and -18.7 cm^2 in Combined (p=0.023 versus control). Combined training reduced ApoB levels 0.81± 0.02 to 0.78 ± 0.02 g/L (p= 0.044 versus controls) and ApoB/ApoA-1 ratio 0.66 ± 0.02 to 0.64 ± 0.02 (p=0.019 versus controls and p=0.038 versus Aerobic). There were no changes in VAT, ApoA1 or HSCRP levels between groups. **Conclusion:** Aerobic training, resistance training and combined training decreased abdominal subcutaneous fat in overweight and obese adolescents. Combined training demonstrated the greatest improvements in non-traditional cardiovascular disease risk factors ApoB and ApoB/ApoA-1 ratio.

Keywords: exercise, obesity, visceral fat, subcutaneous fat, cardiometabolic risk factors

INTRODUCTION

The increased prevalence of abdominal obesity from 1.8% in 1981 to 12.8% in 2007-2009 in Canadian adolescents aged 12 to 19 years old[1] is of particular concern given the strong relationship between increased abdominal fat and cardiovascular disease (CVD) risk factors in youth.[2] Specifically higher levels of visceral fat,[3-4] and adipose tissue in the deep layer of the abdominal subcutaneous region,[5-6] are associated with a more adverse cardiometabolic risk profile.

Elevated high-sensitivity C-reactive protein (HSCRP), a marker of inflammation, is associated with obesity[7-9] and low fitness levels in obese youth[10] and has emerged as a strong independent non-traditional CVD risk factor.[11-12] Apolipoproteins A-1 and B (ApoA-1 and ApoB), play important roles in lipid metabolism and are known as independent predictors of ischemic heart disease in adults.[13] The multinational INTERHEART study found the ApoB/ApoA-1 ratio was the single greatest differentiator between myocardial infarction cases and controls, accounting for 49.2% of population attributable risk of myocardial infarction after adjustment for all other measured risk factors,[14] far more than accounted for by traditional lipids in the same study.[15] In a recent meta-analysis,[16] HSCRP (Relative Risk (RR): 2.43, 95% confidence interval (CI): 2.10–2.83), ApoB (RR: 1.99, 95% CI: 1.65–2.39), and ApoA-1/ApoB ratio (RR: 1.86, 95%CI: 1.55–2.22) emerged as three non-traditional biomarkers associated with the greatest risk of CVD in populations without pre-existing CVD.

Aerobic exercise (e.g. jogging, elliptical training, skipping etc.) and resistance exercise (use of free weights, weight machines, etc.) have been shown to reduce body fat in adolescents,[17] however to our knowledge no study has been performed to identify which exercise training modality is most effective at reducing both abdominal fat and associated CVD risk factors such as HSCRP, ApoB and the ApoB/ApoA-1 ratio in overweight and obese adolescents. Understanding the changes in abdominal fat distribution and associated CVD risk factors following exercise training could provide insights into mechanisms through which aerobic and resistance exercise might reduce cardiometabolic disease risk in youth.

Thus, the purpose of the present study was to investigate the effects of aerobic training, resistance training and their combination on abdominal fat (superficial SAT, deep SAT and VAT), HSCRP, ApoA-1 and ApoB levels and the ApoB/ApoA-1 ratio in overweight and obese adolescents. This paper investigates abdominal fat distribution and non-traditional CVD risk factors as secondary outcomes of the HEARTY (Healthy Eating Aerobic and Resistance Training in Youth) randomized controlled trial, which has been described in detail elsewhere.[18] We hypothesized *a priori* that aerobic and resistance exercise would each reduce abdominal fat, HSCRP, ApoB, and ApoB/ApoA-1 ratio, and combined aerobic and resistance exercise training would do so to a greater extent than either modality alone.

METHODS

Participants

After a 4-week run-in period to assess adherence, 304 inactive post-pubertal overweight and obese adolescents with body mass index (BMI) > 85th percentile for age and sex, aged 14-18 years old were randomized into one of 4 groups for 22 weeks: 1. aerobic training (Aerobic, n=74), 2. resistance training (Resistance, n=75), 3. combined aerobic and resistance training (Combined, n=74) or 4. non-exercising control (Control, n=74). The great majority (92.7%) were obese (>95th percentile for age and sex); those in the 85-94th percentiles were required to have at least one cardiometabolic risk factor aside from obesity.[18]

Intervention

The diet and exercise program have been described in detail elsewhere [18]. Briefly, participants in all 4 groups were given guidance on healthy eating by a registered dietitian which, if followed, would result in a small daily energy intake restriction of 250 kcal below requirements for weight maintenance. All participants initially entered a 4-week run-in program of low volume, moderate-intensity combined aerobic and resistance training aimed at assessing adherence and orienting participants to the exercise programs. During run-in, participants exercised 4 times per week for 4 weeks at an aerobic intensity of 65% of their pre-determined maximum heart rate for 15-30 minutes per session and 1-3 sets of 7 exercises at 15 repetitions maximum for the resistance exercise component. Participants who maintained ≥80% adherence during run-in were randomized to one of 4 groups for 22 weeks (weeks 5-26). Participants randomized to the three exercise groups exercised 4 times per week for an additional 22 weeks and were supervised by personal trainers once per week for the duration of the intervention at local YMCAs and Nautilus Plus gyms in the Ottawa/Gatineau, Canada region. Participants in the aerobic exercise group trained on a treadmill, cycle ergometer or elliptical at an intensity of 70-85% of their maximum heart rate for 20-40 minutes per session for 22 weeks. The resistance exercise group performed whole-body exercises on resistance machines for 6-15 repetitions at the maximum load possible for that number of repetitions for 22 weeks. The combined training group performed both the aerobic component and the resistance component during each exercise session for a maximum of 4 times per week for 22 weeks. The participants in the control group were asked to revert to their baseline activity levels and were offered a postponed exercise program of their choice after the 22 week intervention period.

Body composition

Body composition was assessed by Magnetic Resonance Imaging (MRI) (General Electric, 1.5 Tesla scanner, version signal 11 with echo speed gradients, Milwaukee, WI) at baseline and at 6 months. The participants lay prone during the acquisition of 42–48 whole body cross-sectional images using established protocols by Ross et al.[19-20] The raw MRI data collected from technicians were then transferred to a stand-alone computer workstation to analyze the images using Slice-o-matic software V. 4.3 (Tomovision, Magog, QC, Canada) to quantify total and regional body composition. Abdominal subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) were quantified in cm^2 at the level between the 4th and 5th lumbar vertebra (L4-L5). Deep and superficial compartments of subcutaneous adipose tissue (deep and superficial SAT) were delineated by the fascia superficialis or Scarpa's fascia at the level of L4-L5.

HSCRP and apolipoproteins

All baseline, 3 and 6 months blood measurements were done after 12-hour fasted conditions. Participants were asked to refrain from vigorous physical activity or the use of anti-inflammatory or other medications for 24 hours before the blood sampling. ApoA-1 and ApoB were measured using immunoturbidimetric assays (Beckman Coulter Unicel®DxC600 Synchron® Clinical System and Beckman reagents Beckman Coulter, Inc., Brea, California). HSCRP was measured using highly sensitive Near Infrared Particle Immunoassay rate methodology (Beckman Coulter Unicel®DxC600 Synchron® Clinical System and Beckman reagents Beckman Coulter, Inc., Brea, California).

Statistical analysis

We performed analyses on an intention-to-treat basis and included all randomly allocated participants (including those who later withdrew). We used linear mixed-effects modeling for repeated measures over time with L4-L5 SAT, deep SAT, superficial SAT, L4-L5 VAT, ApoA-1, ApoB, ApoB/ApoA-1, HSCRP) as the dependent variables and effects for time (baseline, 3 months, 6 months), group [Aerobic, Resistance, Combined, Control], and time by group interaction, with age, and sex as covariates and an unstructured covariance matrix. Within the mixed model, we used 95% confidence intervals and p-values for the 4 prespecified intergroup comparisons (Aerobic vs. control, Resistance vs. control, Combined training vs. Aerobic, Combined vs. Resistance), and for changes in dependent variables within each group over time. We also examined the effect of the exercise intervention with per-protocol analyses in participants who had complete baseline and follow-up data and maintained at least 70% exercise adherence (≥2.8 sessions/week) throughout the intervention following the same procedures as in the intention-to-treat analyses. We used SAS, version 9.2 (SAS Institute, Cary, North Carolina), for all analyses.

RESULTS

From baseline to 26 weeks, the median exercise training adherence was 62% (interquartile range, 36% to 81%) in the aerobic group, 56% (interquartile range, 37% to 75%) in the resistance group and 64% (interquartile range, 39% to 75%) in the combined group. Seventy five participants (25%) withdrew between randomization and 6 months: 18 (24%) aerobic training participants, 21 (28%) resistance training participants, 17 (23%) combined training participants, and 19 (25%) control participants.

Abdominal fat

Table 1 describes the baseline physical characteristics of the participants, and Table 2 displays the changes in abdominal fat distribution following the intervention. Total SAT at L4-L5 decreased within all three exercise groups and changes were significantly different in Aerobic vs. Control and in Resistance vs. Control. Superficial SAT decreased in Resistance compared to Control. Abdominal deep SAT decreased in Aerobic vs. Control. VAT changes did not differ significantly among groups. In per-protocol analyses, there were within-group decreases in deep SAT in Aerobic and Combined but only the decreases in Aerobic were significantly different from Control. VAT decreased from baseline to post-intervention in the combined training group only, without any changes between groups.

Apolipoproteins and HSCRP

Table 3 displays ApoA-1, ApoB, ApoB/ApoA-1 and HSCRP at baseline, 3 and 6-months post-randomization. The Combined group reduced ApoB levels (p= 0.044 versus controls) and ApoB/ApoA-1 ratio (p=0.019 versus controls and p=0.038 versus Aerobic). There were no intergroup differences in ApoA-1, or HSCRP following the intervention. Per-protocol analyses revealed no significant between-group differences.

DISCUSSION

The major findings of the current investigation were that aerobic training, resistance training and combined training decreased abdominal SAT and combined training reduced the ApoB/ApoA-1 ratio more than aerobic training alone. This study is also the first to examine the separate and combined effects of aerobic and resistance exercise training modalities on both deep and superficial abdominal SAT in obese adolescents.

Compared with controls, our results showed decreases in abdominal SAT at the level of L4-L5 in all three exercise groups. These results are consistent with those of a recently-published shorter (3 months) and smaller (n=45) randomized controlled trial in obese adolescent males.[17] On the other hand, we did not find decreases in VAT in any of the groups (exercise or control), in contrast to this other trial.[17] The absence of a significant decrease in VAT observed in our study could partly be explained by the fact that our sample was composed of 70% females versus 100% males in Lee et al's study.[17] Typically males have more VAT than females[21] and thus have the potential to exhibit larger reductions in this abdominal fat depot. Furthermore, the participants in Lee et al's study showed greater adherence (~99%) [17] compared to the participants of the current study. When we analyzed the data of only the most adherent participants who completed more than 70% of the prescribed exercise sessions, only the combined group showed within-group decreases in VAT following training but these changes were not significant between groups. When we restricted analysis to males-only, we still found no significant decreases in VAT (data not shown). While body fat distribution is influenced by genetics,[22-23] the influence of nutrition and hypocaloric diet warrants further study in youth[24]. Although in our study a dietitian provided dietary counseling with a maximum daily deficit of 250 kcal, these recommendations in addition to the increased energy expenditure associated with our exercise stimulus may not have been sufficient to induce drastic decreases in weight and consequently in VAT in overweight and obese adolescents. Furthermore, in a separate report we showed that resting energy expenditure (which accounts for 50-70% of total energy expenditure in obese adolescents)[25] did not change in any group following training (manuscript 7 of this dissertation).

Although there were significant within-group decreases in deep SAT following aerobic training and combined training, only the most adherent participants in the aerobic training group had decreases in the deep layer of abdominal SAT compared to controls. The deep layer of SAT is characterized by irregular and disorganized fat lobules[26]. Similarly to VAT, deep SAT has been associated with greater cardiometabolic risk than the superficial SAT depot.[5, 27-28] Our results suggest regular aerobic training could produce reductions in cardiometabolic risk through reductions in the deep SAT depot of obese adolescents.

To our knowledge, this is the first randomized controlled trial to investigate the effects of aerobic training, resistance training and combined exercise training on ApoA-1, ApoB and ApoB/ApoA-1 ratio in overweight and obese adolescents. The results of the current study showed that the decrease in ApoB/ApoA-1 ratio was greater in combined training compared to aerobic training alone. However, there were no significant changes in ApoA-1 or HSCRP levels following the intervention. It has been proposed that subcutaneous adipose tissue releases the adipokine interleukin-6 (IL-6),[29] which then stimulates the release of acute phase-protein and sensitive biomarker of systemic inflammation, HSCRP and fibrinogen from the liver[30]. Increased concentrations of IL-6,[31] fibrinogen,[31-32] and HSCRP,[31-32] have been reported in obese adolescents compared to their leaner peers and may play roles in endothelial dysfunction, thrombogenesis and the progression of CVD[33-34]. Previous interventions with obese adolescents have shown reductions[31-32, 35-37] or no changes[10, 38-39] in HSCRP following aerobic exercise training. To our knowledge, only one study[40] evaluated the effects of a 12-week circuit-based combined aerobic and resistance training intervention (2 sessions/week of 45-60 min at 65-85% HR_{max}) and found that HSCRP remained unchanged in 13-14 year old obese males. It has been suggested that a decrease in body fat mass is necessary to decrease HSCRP levels.[32] Although we previously reported significant decreases in percent body fat in the resistance training group (-1.6%) and in the combined training group (-1.4%) in this trial (main HEARTY results manuscript 5), the body weight changes were modest compared to studies that have reported much larger decreases in percent body fat (-3.6 to 6.3%) following aerobic training[31, 36] with concomitant improvements in HSCRP levels. Also, the decrease in body fat mass in our aerobic training group was not significantly different from control and this could explain why we did not observe a decrease in HSCRP levels. On average, our participants had normal HSCRP levels and glucose tolerance at baseline giving another potential explanation as to why we did not observe changes in HSCRP levels through any exercise training modality. Exercise adherence could have been a factor explaining the lack of significant changes in non- traditional CVD risk factors, however, we observed essentially the same results in per-protocol analyses (≥70% exercise adherence) and intention-to–treat analyses.

Our findings show that aerobic and resistance exercise training resulted in the greatest reductions in abdominal obesity, and combined training reduced ApoB and ApoB/ApoA-1 ratio in overweight and obese adolescents.

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CONFLICT OF INTEREST

The authors disclose no conflicts of interest.

TABLE 1. Baseline physical characteristics of participants.

	Total sample	Aerobic	Resistance	Combined	Control
Sample size, N	304	75	78	75	76
Males, N (%)	91 (30)	22 (29)	23 (29)	22 (29)	24 (32)
Females, N (%)	213 (70)	53 (71)	55 (71)	53 (71)	52 (68)
Age (years)	15.6 (1.4)	15.5 (1.4)	15.9 (1.5)	15.5 (1.3)	15.6 (1.3)
Weight (kg)	98 (16.9)	96.7 (15.1)	99.9 (17.4)	97.5 (16.3)	97.9 (18.8)
Height (cm)	167.8 (7.4)	166.8 (7.0)	168.3 (7.5)	167.5 (7.6)	168.8 (7.7)
Body Mass Index (kg/m^2)	34.6 (4.5)	34.7 (4.2)	35.1 (4.6)	34.6 (4.2)	34.1 (4.9)
Waist circumference (cm)	96.8 (11)	96.4 (10.1)	98.8 (11.4)	96.8 (10.5)	95.2 (11.8)
Body fat (%)	49.5 (5.6)	49.1 (5.8)	49.9 (5.8)	50.3 (5.3)	48.6 (5.3)

Values are means (SD).

TABLE 2. Changes in abdominal fat distribution at baseline and after 3 and 6 months.

		Mean (SE)		Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
INTENTION-TO-TREAT ANALYSIS					
SAT (cm^2)					
Aerobic	74	474.3 (15.3)	458.0 (16.8)	-16.2 (-31.3, -1.1)*	
Resistance	75	485.7 (15.3)	463.0 (16.7)	-22.7 (-37.6, -7.7)*	
Combined	74	489.0 (15.3)	470.3 (16.7)	-18.7 (-33.7, -3.7)*	
Control	74	457.7 (15.3)	463.3 (16.7)	5.6 (-9.1, 20.3)	
Aerobic vs. control					-21.8 (-42.9, -7.3)*
Resistance vs. control					-28.3 (-49.3, -7.3)**
Combined vs. aerobic					-2.5 (-23.8, 18.8)
Combined vs. resistance					4.0 (-17.2, 25.1)
Superficial SAT (cm^2)					
Aerobic	59	225.9 (8.8)	221.9 (9.2)	-3.9 (-13.7, 5.9)	
Resistance	59	234.9 (8.8)	225.2 (9.2)	-9.7 (-19.4, 0.1)	
Combined	59	232.6 (8.8)	222.8 (9.2)	-9.8 (-19.5, -0.1)*	
Control	61	215.5 (8.6)	220.6 (8.9)	5.1 (-4.3, 14.4)	
Aerobic vs. control					-9.0 (-22.6, 4.6)
Resistance vs. control					-14.7 (-28.2, -1.3)*
Combined vs. aerobic					-5.9 (-19.7, 8.0)
Combined vs. resistance					-0.1 (-13.9, 13.6)

Deep SAT (cm^2)					
Aerobic	59	249.4 (9.4)	237.6 (10.9)	-11.8 (-22.1, 1.4)*	
Resistance	59	255.9 (9.5)	247.1 (11.0)	-8.8 (-19.0, 1.5)	
Combined	59	241.9 (9.4)	233.2 (10.9)	-8.8 (-19.0, 1.5)	
Control	61	224.6 (9.3)	228.2 (10.7)	3.6 (-6.2, 13.4)	
Aerobic vs. control					-15.3 (-29.6, -1.1)*
Resistance vs. control					-12.3 (-26.5, 1.9)
Combined vs. aerobic					2.9 (-11.6, 17.5)
Combined vs. resistance					-0.0 (-14.5, 14.5)
VAT at L4L5 (cm^2)					
Aerobic	74	75.3 (2.9)	75.1 (3.7)	-0.2 (-5.1, 4.7)	
Resistance	75	77.2 (2.9)	73.2 (3.7)	-4.0 (-8.8, 0.8)	
Combined	74	76.4 (2.9)	72.5 (3.7)	-3.9 (-8.7, 1.0)	
Control	74	77.3 (2.9)	76.4 (3.7)	-0.9 (-5.6 , 3.9)	
Aerobic vs. control					0.6 (-6.2, 7.5)
Resistance vs. control					-3.1 (-9.9, 3.6)
Combined vs. aerobic					-3.7 (-10.5, 3.2)
Combined vs. resistance					0.1 (-6.7, 7.0)

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SAT (cm^2)					
Aerobic	35	457.2 (22.2)	436.8 (23.6)	-20.4 (-40.3, -0.5)*	
Resistance	23	511.4 (27.4)	489.8 (29.1)	-21.6 (-46.2, 2.9)	
Combined	29	494.0 (24.6)	452.5 (26.1)	-41.5 (-63.3, -19.6)***	
Control	74	456.8 (15.3)	462.5 (16.7)	5.8 (-9.8, 21.4)	
Aerobic vs. control					-26.2 (-51.5, -0.9)*
Resistance vs. control					-27.4 (-56.5, 1.7)
Combined vs. aerobic					-21.1 (-50.7, 8.5)
Combined vs. resistance					-19.8 (-52.7, 13.1)
Superficial SAT (cm^2)					
Aerobic	29	207.8 (10.9)	201.6 (11.5)	-6.2 (-18.9, 6.5)	
Resistance	17	259.2 (14.2)	249.5 (14.9)	-9.7 (-26.0, 6.6)	
Combined	20	233.5 (13.3)	208.3 (14.1)	-25.2 (-40.6, -9.8)**	
Control	61	214.6 (7.6)	219.7 (8.3)	5.1 (-4.7, 14.9)	
Aerobic vs. control					-11.3 (-27.4, 4.7)
Resistance vs. control					-14.8 (-33.8, 4.2)
Combined vs. aerobic					-19.0 (-39.0, 1.0)
Combined vs. resistance					-15.5 (-37.9, 6.9)

Deep SAT (cm^2)					
Aerobic	29	241.5 (13.7)	226.4 (15.7)	-15.2 (-28.9, -1.5)*	
Resistance	17	263.6 (17.9)	256.9 (20.4)	-6.7 (-24.3, 10.9)	
Combined	20	242.3 (16.8)	219.8 (19.1)	-22.5 (-39.1, -5.8)**	
Control	61	224.1 (9.6)	227.6 (11.1)	3.5 (-7.1, 14.1)	
Aerobic vs. control					-18.7 (-36.0, -1.3)*
Resistance vs. control					-10.1 (-30.7, 10.4)
Combined vs. aerobic					-7.3 (-28.9, 14.3)
Combined vs. resistance					-15.8 (-40.0, 8.4)
VAT (cm^2)					
Aerobic	35	72.3 (4.2)	72.3 (4.8)	0.1 (-5.9, 6.0)	
Resistance	23	85.3 (5.1)	83.0 (5.9)	-2.4 (-9.7, 5.0)	
Combined	29	74.1 (4.6)	65.9 (5.3)	-8.2 (-14.7, -1.6)*	
Control	74	77.8 (2.9)	77.0 (3.5)	-0.8 (-5.4, 3.9)	
Aerobic vs. control					0.9 (-6.7, 8.4)
Resistance vs. control					-1.6 (-10.2, 7.1)
Combined vs. aerobic					-8.2 (-17.0, 0.6)
Combined vs. resistance					-5.8 (-15.6, 4.0)

*p<0.05, **p<0.01, ***p<0.001.

Note: SAT = subcutaneous adipose tissue, VAT = visceral adipose tissue.

Table 3. Changes in Apolipoproteins A-1 and B, ApoB/ApoA-1 ratio and high sensitivity C- reactive protein at baseline and after 3, and 6 months.

		Mean (SE)			Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**3 months**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
INTENTION-TO-TREAT ANALYSIS						
Apolipoprotein A-1 (g/L)						
Aerobic	75	1.22 (0.02)	1.22 (0.02)	1.21 (0.03)	-0.01 (-0.05, 0.03)	
Resistance	77	1.25 (0.02)	1.24 (0.02)	1.26 (0.03)	0.01 (-0.03, 0.05)	
Combined	75	1.23 (0.02)	1.24 (0.02)	1.24 (0.02)	0.01 (-0.02, 0.05)	
Control	76	1.24 (0.02)	1.26 (0.02)	1.23 (0.03)	-0.01 (-0.05, 0.03)	
Aerobic vs. control						0 (-0.06, 0.05)
Resistance vs. control						0.02 (-0.04, 0.07)
Combined vs. aerobic						0.02 (-0.03, 0.08)
Combined vs. resistance						0 (-0.05, 0.06)

Apolipoprotein B (g/L)						
Aerobic	75	0.8 (0.02)	0.8 (0.02)	0.81 (0.02)	0.01 (-0.02, 0.04)	
Resistance	77	0.82 (0.02)	0.82 (0.02)	0.81 (0.02)	-0.01 (-0.04, 0.02)	
Combined	75	0.81 (0.02)	0.8 (0.02)	0.78 (0.02)	-0.03 (-0.06, 0)	
Control	76	0.84 (0.02)	0.85 (0.02)	0.85 (0.02)	0.01 (-0.02, 0.05)	
Aerobic vs. control						0 (-0.05, 0.04)
Resistance vs. control						-0.03 (-0.07, 0.02)
Combined vs. aerobic						-0.04 (-0.09, 0)
Combined vs. resistance						0.02 (-0.02, 0.07)

ApoB/ApoA1						
Aerobic	75	0.67 (0.02)	0.67 (0.02)	0.68 (0.02)	0.01 (-0.02, 0.04)	
Resistance	77	0.67 (0.02)	0.68 (0.02)	0.65 (0.02)	-0.01 (-0.04, 0.01)	
Combined	75	0.67 (0.02)	0.66 (0.02)	0.64 (0.02)	-0.03 (-0.05, 0)*	
Control	76	0.69 (0.02)	0.69 (0.02)	0.71 (0.02)	0.01 (-0.01, 0.04)	
Aerobic vs. control						0 (-0.04, 0.03)
Resistance vs. control						-0.03 (-0.06, 0.01)
Combined vs. aerobic						-0.04 (-0.07, 0)*
Combined vs. resistance						-0.01 (-0.05, 0.02)

High-sensitivity C-reactive protein (mg/L)†						
Aerobic	75	2.61 (0.33)	2.35 (0.31)	2.23 (0.32)	-0.39 (-0.85, 0.19)	
Resistance	77	2.64 (0.33)	2.42 (0.31)	2.26 (0.33)	-0.38 (-0.86, 0.23)	
Combined	75	1.95 (0.25)	1.81 (0.23)	1.90 (0.27)	-0.05 (-0.43, 0.44)	
Control	76	2.24 (0.28)	1.88 (0.25)	1.98 (0.28)	-0.26 (-0.67, 0.25)	
Aerobic vs. control						-3.36 (-29.89, 33.20)
Resistance vs. control						-2.87 (-29.96, 34.69)
Combined vs. aerobic						14.61 (-16.58, 57.48)
Combined vs. resistance						14.04 (-17.51, 57.65)

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Apolipoprotein A-1 (g/L)						
Aerobic	35	1.22 (0.03)	1.21 (0.04)	1.18 (0.04)	-0.04 (-0.09, 0.01)	
Resistance	22	1.21 (0.04)	1.24 (0.04)	1.26 (0.04)	0.05 (-0.01, 0.11)	
Combined	29	1.3 (0.04)	1.26 (0.04)	1.29 (0.04)	-0.01 (-0.06, 0.05)	
Control	76	1.24 (0.02)	1.26 (0.03)	1.23 (0.03)	-0.01 (-0.05, 0.03)	
Aerobic vs. control						-0.03 (-0.09, 0.03)
Resistance vs. control						0.06 (-0.01, 0.13)
Combined vs. aerobic						0.03 (-0.04, 0.1)
Combined vs. resistance						-0.06 (-0.14, 0.02)

Apolipoprotein B (g/L)						
Aerobic	35	0.78 (0.03)	0.76 (0.04)	0.79 (0.04)	0.01 (-0.03, 0.05)	
Resistance	22	0.82 (0.04)	0.84 (0.04)	0.81 (0.04)	0 (-0.05, 0.05)	
Combined	29	0.81 (0.04)	0.78 (0.04)	0.78 (0.04)	-0.03 (-0.07, 0.02)	
Control	76	0.84 (0.02)	0.85 (0.03)	0.85 (0.03)	0.01 (-0.02, 0.04)	
Aerobic vs. control						0 (-0.05, 0.05)
Resistance vs. control						-0.01 (-0.07, 0.05)
Combined vs. aerobic						-0.03 (-0.09, 0.02)
Combined vs. resistance						-0.02 (-0.09, 0.04)

ApoB/ApoA1 ratio						
Aerobic	35	0.66 (0.03)	0.65 (0.03)	0.67 (0.03)	0.02 (-0.02, 0.05)	
Resistance	22	0.69 (0.04)	0.69 (0.04)	0.66 (0.04)	-0.03 (-0.07, 0.02)	
Combined	29	0.63 (0.04)	0.62 (0.04)	0.62 (0.04)	-0.01 (-0.05, 0.03)	
Control	76	0.7 (0.02)	0.69 (0.02)	0.71 (0.02)	0.01 (-0.02, 0.04)	
Aerobic vs. control						0.01 (-0.03, 0.05)
Resistance vs. control						-0.04 (-0.09, 0.01)
Combined vs. aerobic						-0.03 (-0.08, 0.02)
Combined vs. resistance						0.02 (-0.04, 0.07)

High-sensitivity C-reactive protein (mg/L)†						
Aerobic	35	2.63 (0.51)	1.93 (0.37)	1.89 (0.39)	-0.74 (-1.23, -0.08)*	
Resistance	22	2.17 (0.52)	2.27 (0.53)	2.28 (0.58)	0.10 (-0.61, 1.15)	
Combined	29	1.79 (0.38)	1.44 (0.30)	1.36 (0.30)	-0.43 (-0.81, 0.10)	
Control	76	2.27 (0.30)	1.88 (0.26)	1.94 (0.29)	-0.33 (-0.74, 0.18)	
Aerobic vs. control						-15.82 (-41.99, 22.14)
Resistance vs. control						22.88 (-20.67, 90.36)
Combined vs. aerobic						5.69 (-31.68, 63.50)
Combined vs. resistance						-27.60 (-55.81, 18.60)

*p<0.05, **p<0.01, ***p<0.001.

Note: ApoA1= Apolipoprotein A1, ApoB= Apolipoprotein B.

†Values were log-transformed for analysis; geometric means are presented.

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Exercise training and resting metabolic rate in obese adolescents: the HEARTY trial

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Running title: Exercise and RMR in obese adolescents

ABSTRACT

Purpose: To examine the effects of aerobic training, resistance training, and their combination on resting metabolic rate in overweight and obese adolescents. **Methods:** After a 4-week supervised moderate-intensity exercise run-in period, 304 postpubertal obese (BMI ≥95th BMI percentile) or overweight (≥85th percentile + additional diabetes risk factor) adolescents aged 14–18 years were randomized to 4 groups for 22 weeks: Aerobic training, Resistance training, Combined training, or a non-exercising Control. All participants received dietary counseling targeting a daily energy deficit of 250 kcal. Resting energy expenditure was measured by indirect calorimetry and body composition (fat mass, fat-free mass) by magnetic resonance imaging. **Results:** Despite improvements in body composition, absolute RMR did not change significantly from baseline to 6 months in any group (Aerobic: 1972 ± 38 to 1990 ± 41; Resistance: 2024 ± 37 to 1992 ± 41; Combined: 2023 ± 38 to 1995 ± 38 and Control: 2075 ± 38 vs. 2073 ± 39 kcal/day). Absolute RMR did not change after adjustment for fat-free mass or total body weight between groups over time. **Conclusion:** aerobic training, resistance training or combined training did not significantly alter the RMR of obese adolescents following a 6-month intervention. The addition of exercise to a small dietary restriction program did not increase resting energy expenditure in obese adolescents. Increasing resting energy expenditure, is therefore an unlikely mechanism for weight loss when participating in an exercise program.

Keywords: aerobic exercise, resistance exercise, resting energy expenditure, metabolism

INTRODUCTION

Paragraph Number 1 Rates of childhood and adolescent obesity have risen dramatically over the last two decades (27). Obesity is the result of an imbalance between energy intake and energy expenditure. Resting metabolic rate (RMR), is defined as the rate at which the body expends energy (calories) at rest reflecting the body's heat production in the postabsorptive state and accounts for approximately 50-70% of total daily energy expenditure in obese adolescents (19). Dietary restriction is typically associated with decreases in RMR (38). Fat-free mass (organs, lean tissue and skeletal muscle) accounts for the majority of the variation in RMR (60-80% of the individual variation) in obese children and adolescents (15, 25-26, 28) and resistance training increases fat-free mass (32, 34-35), specifically skeletal muscle (20) in obese youth. Therefore, increasing RMR (or preventing a decrease) by adding resistance training to a modest dietary restriction could have important implications for energy balance regulation and weight maintenance in obese youth.

Paragraph Number 2 Previous research examining the effects of long-term exercise training on RMR in obese adolescents is very limited (13, 19). No studies have compared the effects of aerobic training alone, resistance training alone and combined training on RMR in a large sample of obese adolescents.

Paragraph Number 3 The aim of the present study was to examine the effects of 6 months of aerobic training, resistance training and their combination on RMR in overweight and obese adolescents. We hypothesized *a priori* that both the resistance training and combined training groups would increase RMR to a similar extent, while no changes would be observed in the aerobic-only or non-exercising control group.

METHODS

Paragraph Number 4 *Participants* This paper investigates RMR as a secondary outcome of the large randomized controlled trial entitled HEARTY (Healthy Eating Aerobic and Resistance Training in Youth) which has been described in detail elsewhere (1). This study was reviewed and approved by the Research Ethics Boards at the Children's Hospital of Eastern Ontario and the Ottawa Hospital, Ottawa, Canada. After a 4-week run-in period to assess adherence, 304 inactive postpubertal obese [BMI $\geq 95^{th}$ BMI (body mass index) percentile] or overweight [≥85th BMI percentile + an additional diabetes risk factor] adolescents aged 14-18 years old were randomized into 4 groups for 22 weeks: 1. aerobic training (Aerobic, n= 75), 2. resistance training (Resistance, n= 78), 3. combined aerobic and resistance training (Combined, n= 75) or 4. non-exercising control (Control, n= 76). All participants received dietary counseling targeting a daily energy deficit of 250 kcal.

Paragraph Number 5 Intervention Details of the diet and exercise programs were published previously (1). Briefly, participants in all 4 groups were given healthy nutrition guidelines by a registered dietitian including a small daily energy intake restriction of 250 kcal below requirements for weight maintenance. All participants entered a 4-week pre-randomization run-in period including combined aerobic and resistance exercise training aimed at assessing adherence and habituation to the exercise. During run-in, participants exercised 4 times per week at an intensity of 65% of their measured maximum heart rate (HR_{max}) for 15-30 minutes per session of aerobic exercise and performed 1-3 sets of 15 reps for the resistance training component. Only participants who maintained ≥80% adherence during run-in were randomized. Participants randomized to the three intervention groups were asked to exercise 4 times per week for an additional 22 weeks and were supervised at local YMCAs and Nautilus Plus gyms. Exercise was supervised by personal trainers twice per week during run-in, once per week from randomization to 3 months and then once every two weeks from 3 months to 6 months. Participants in the aerobic training group exercised on a treadmill, cycle ergometer or elliptical machine at an intensity of 70-85% of their HR_{max} for 20-40 minutes per session. The resistance training group performed whole-body exercises on resistance machines for 6-15 repetitions of their maximum for 20-40 minutes per session. The combined training group performed both the aerobic and the resistance components during each exercise session for a maximum of 4 times per week for 22 weeks. The participants in the control group were instructed to revert back to their baseline activity levels. As an incentive, all participants (exercise and control) were offered the exercise program of their choice after completion of all 6-month (post-intervention) measures.

Paragraph Number 6 Anthropometry and Body Composition Weight (kg) and height (cm) were measured using a Health O Meter manual scale (Health O Meter, Continental Scale Corp., Bridgeview, IL) and a stadiometer respectively. BMI was calculated as [weight (kg)]/ [height (m^2)]. Body composition was assessed by Magnetic Resonance Imaging (MRI) (General Electric, 1.5 Tesla scanner, version signal 11 with echo speed gradients, Milwaukee, WI) at baseline and at 6 months. The participants lay prone during the acquisition of 42–48 whole body cross-sectional images using established protocols by Ross et al. (21, 29). MRI images were analyzed using Slice-o-matic software V. 4.3 (Tomovision, Magog, QC, Canada) to quantify fat mass and fat-free mass.

Paragraph Number 7 Resting Metabolic Rate (RMR) Resting metabolic rate measurements were conducted at baseline and at 6 months. Participants arrived at the laboratory between 7 00 h and 11 00 h after a 12-hour fast. Participants were instructed to sleep for eight hours the night before testing, and to avoid exercise 48 hours prior to their testing session. Oxygen consumption was measured by indirect calorimetry using an automated metabolic system (MOXUS Modular Metabolic System, AEI Technologies Naperville, IL, USA) for a 20-minute data collection period in a temperature controlled room at 21-23 ˚C. Absolute RMR (kilocalories/day) was then calculated using the Weir equation (39).

STATISTICAL ANALYSIS

Paragraph Number 8 Baseline participant characteristics were summarized as mean and standard deviation for continuous data, and count and percentage for categorical data for the entire population and each treatment group (Table 1). Analyses were intention-to-treat (including participants who later withdrew from the HEARTY trial). Linear mixed-effects models for repeated measures were used, with absolute RMR (kilocalories/day) as the dependent variable and time, study group, and time-by-group interaction as primary predictors, adjusting for age and sex. We used the same procedures to assess the effect of intervention groups on body composition including percent body fat, fat mass, fat-free mass and skeletal muscle. We ran additional models in which fat-free mass and total body weight were entered as separate covariates in addition to time, study group, time-by-group interaction, age and sex. From the mixed models, we estimated 95% confidence intervals (CI) and *P*-values for the 4 intergroup comparisons (Aerobic versus control, Resistance versus control, Combined versus Aerobic, Combined versus Resistance) for change in absolute RMR between baseline and 6 months and over time within each group. Stratified analyses were also performed for males and females separately (adjusting for age). P-values of 0.05 or less were considered statistically significant. The intention-to-treat total sample included 299 participants. Secondary 'per-protocol' analyses were also conducted including only the participants who attended ≥70% of the prescribed exercise sessions throughout the intervention and completed baseline and 6-month RMR testing (per-protocol sample n= 163), using the same procedures described for the intention-to-treat analyses. All analyses were performed using the statistical software package SAS 9.2 (Cary, NC).

RESULTS

Paragraph Number 9 There were no significant baseline differences between groups on all variables presented in this paper (Table 1). Of the 358 participants who entered the run-in phase, 304 (84.9%) were randomized. The other 54 participants were not randomized due to low adherence during run-in (n=51), a medical condition (n= 2) or moving to another city (n= 1). Of the 304 participants randomized, 103 participants did not attend RMR testing at 6 months (30 in Aerobic, 31 in resistance, 21 in combined and 21 in the control group). Furthermore, 10 participants (2 in Aerobic, 2 in Resistance, 2 in Combined and 4 in the Control group) were not included in the analysis because they did not follow the RMR testing guidelines (they could not keep still and/or they were uncomfortable with the equipment throughout the RMR test).

Fat-Free Mass

Paragraph Number 10 Intention-to-treat analyses showed modest within-group increases in fat-free mass over time in all groups, but no significant intergroup differences (Table 2). Per-protocol analyses revealed similar non-significant trends (Table S1, Supplementary Appendix). When analyses were conducted separately by sex, intention-to-treat analyses in males only showed increases in fat-free mass within all 4 groups but changes did not differ between groups (Table S2, Supplementary Appendix). There were no significant differences in fat-free mass in per-protocol analyses in males only (Table S2, Supplementary Appendix). Intention-to-treat and per-protocol analyses showed no between-group differences in fat free mass in females only (Table S3, Supplementary Appendix). Furthermore, we previously reported that there were no significant differences in energy intake or background physical activity between groups over time in intent-to-treat and per-protocol analyses (manuscript 5 main HEARTY results).

Resting Metabolic Rate

Paragraph Number 11 Absolute RMR was correlated with total body weight ($r= 0.65$, $p<0.001$) and total fat-free mass ($r= 0.44$, $p<0.001$). Absolute RMR (kilocalories/day) did not differ significantly within or between groups over time (Table 2). Likewise, after adjusting for total body weight and total fat-free mass, changes in RMR still did not differ between groups (Figures 1 and 2). Per-protocol analyses, with and without adjustment for total body weight and total fat free mass, also revealed no significant differences in RMR between groups over time (Table S1, Supplementary Appendix). When analyses were conducted separately by sex, RMR did not change significantly in males or in females (Tables S2 and S3, Supplementary Appendix).

DISCUSSION

Paragraph Number 12 The major finding of the present study was that, contrary to our hypothesis, the addition of aerobic training, resistance training or combined training to a small dietary restriction intervention did not increase resting energy expenditure in obese adolescents. Per-protocol analyses including only participants with ≥70% adherence to our prescribed 4 sessions/week showed the same trends-- no differences in total fat-free mass and RMR between groups following the exercise training interventions.

***Paragraph Number* 13** This is the first randomized controlled trial to compare the effects of different types of exercise modalities on RMR in obese postpubertal adolescents. The results of the current study are in line with our previous findings in mostly-obese adults with type 2 diabetes, that 6 months of aerobic training, resistance training and combined training caused no changes in RMR (with or without adjustment for fat-free mass) or in fat-free mass (16) despite improvements in glycemic control and cardiorespiratory fitness (17-18, 33).

Paragraph Number 14 However, our results differ from those of Lazzer et al. (19) who showed a decreases in RMR in 26 obese adolescents (aged 12-16 years old) after a 9-month multidisciplinary weight reduction intervention including moderate energy restriction (~15-20% less than the estimated daily energy expenditure) and a progressive aerobic and resistance training program (2 times/week, 40 min/session). More specifically, the results showed a significant decrease in basal metabolic rate (measured by open-circuit indirect calorimetry in a whole-body calorimeter) in both boys (n=12) (6.00 to 5.56 kJ/min) and girls (n=14) (5.47 to 4.96 kJ/min) ($p<0.001$) even after adjusting for fat-free mass. It is important to note that the intervention by Lazzer et al. showed large reductions in body weight in girls (15.6 kg, $p<0.001$) and in boys (18.4 kg, $p<0.001$) and decreases in fat-free mass in girls (3.3 kg, $p<0.001$) but not in boys (0.4 kg, $p>0.05$) compared to the smaller weight loss (-0.8 kg in the combined group from intention-to-treat analyses) and the non-significant increases in fat-free mass (0.7-1.4 kg) in the current study. This could partly be explained by the greater dietary restriction and closer dietary supervision (one visit weekly) in the Lazzer study. Given the strong relationship between RMR and total body weight as well as fat-free mass, the significant decrease in RMR reported in the Lazzer study could be explained by the greater body weight and fat-free mass loss.

Paragraph Number 15 Foschini et al. (13) evaluated the effects of two types of resistance training (linear periodization by alternating volume and intensity of resistance training every 4 weeks vs. daily undulating periodization by alternating volume and intensity at every exercise session) in combination with aerobic exercise 3 times/week for 60 min/session for 14 weeks in postpubertal obese adolescents aged 16.5 ± 1.7 years old (n= 32; 15 boys; 17girls). The authors found a decrease in RMR (measured by ventilated-hood system indirect calorimetry) in the aerobic plus linear periodization resistance training group (1847.2 ± 407.9 to 1591.7 ± 361.8 kcals/day, $p<0.05$), however these changes were not significantly different from the daily undulating periodization group. Furthermore, the analyses were not adjusted for fat-free mass. These two studies (13),(19) were limited by their non-randomized, non-controlled designs and small samples.

Paragraph Number 16 Byrne and Wilmore (5) investigated the effects of 20 weeks of resistance exercise, or resistance plus aerobic exercise (walking) on the RMR of obese women aged 18-46 years old exercising 4 days per week vs. a non-exercising control group. RMR increased in the resistance exercise group by 3% but declined by 3.8% in the combined resistance and aerobic exercise group from pre to post- intervention. However, when RMR was expressed relative to fat-free mass, the results were no longer significant, suggesting that the increase in RMR following resistance exercise training was attributed to the increase in fat-free mass (+1.9 kg).

Paragraph Number 17 Strong evidence in obese adults has shown that weight loss (often accompanied by fat-free-mass loss) results in decreases in RMR (3, 6-7, 9-11, 30). A systematic review in adults (30) showed that the greatest RMR reduction was observed following diet-only interventions, RMR reduction was correlated with the energy deficit, and was greater in studies of shorter durations. A recent systematic review of 71 studies including 1,450 overweight or obese adults showed that a 9.4 ± 5.5 kg weight loss, was associated with a reduction of RMR of 126.4 ± 78.1 kcal/day (31). If we applied these findings to the adolescent population in the HEARTY trial, the small daily energy restriction prescribed (-250 kcal/day) and the longer duration of our intervention (6 months) coupled with the small decreases in body weight and lack of change in fat-free mass could explain why RMR remained unchanged.

Paragraph Number 18 Although the recent systematic review by Schwartz et al. (30) showed no sex differences in RMR change following weight loss in adults, except with weight loss pharmacotherapy, the possibility of a sex influence on the modulation of RMR in response to weight loss has not been studied in obese adolescents. The HEARTY population consisted of 70% girls who, at baseline, had lower weight, fat-free mass, aerobic fitness and absolute RMR than the boys. The notion that women have lower absolute RMR than men has been supported in the literature (37). These sex differences also remain when controlled for body cell mass but not after adjustment for fat-free mass (4). Although our RMR results were controlled for sex, when only adherent males and females were analyzed separately, females in the exercise training groups appeared to show less pronounced changes in body composition (smaller increases in fat-free mass and total skeletal muscle) compared to the males in our study. For example, changes in total fat-free mass in the resistance exercise training group from baseline to post-intervention were +1.2 kg ($p<0.01$ compared to baseline) and +3.9 kg ($p>0.05$ compared to baseline) within adherent females and males, respectively. We did not observe statistically significant changes in RMR in either sex, but our statistical power in males was limited.

Paragraph Number 19 Although previous studies found that resistance training increases fat-free mass in obese youth (32, 34-35) and fat-free mass accounts for 60-80% of the individual variation of RMR in obese children and adolescents (15, 25-26, 28), skeletal muscle is a smaller determinant of total calculated resting energy expenditure in healthy adults (22.5 ± 3.4%) than the brain, liver, heart and kidneys (58.0 ± 4.8%) (14). The other contributing components of RMR include the functioning of vital organs such as the heart, lungs, kidneys and liver. Comparing the estimated lower metabolic rate of skeletal muscle (13 kcal/kg/day) to other organs such as the heart and kidney (440 kcal/kg/day) (12), it would necessitate a drastic increase in skeletal muscle mass to significantly increase RMR. Given that, in our participants, total skeletal muscle mass only increased by 0.9 kg in the resistance exercise group and 0.2 kg in the aerobic exercise group, it is not surprising that the RMR did not change following the exercise training intervention.

Paragraph Number 20 Limitations Our study has some limitations. It has been shown that there is a link between sleep and metabolism (2) and adolescents typically sleep less than the recommended nine hours of sleep per night (22). Short sleep duration has been associated with obesity (8) and sleep restriction is related to hormonal imbalances through increased secretion of ghrelin and decreased leptin levels, (36) known to affect energy metabolism. Although we recommended no exercise and 8 hours of uninterrupted sleep per night for 48 hours prior to the RMR testing session, we did not assess the number of hours slept the evening before the testing session. Some studies have also shown that fluctuations in women's menstrual cycles can affect RMR by demonstrating higher rates during the luteal phase (23-24) compared to the follicular phase. However, due to our large sample size, the numerous tests our participants were subjected to, and the fact than many participants had irregular menses, it was not feasible to schedule the testing session based on the menstrual cycle of our female participants. Finally, on average, the adherent participants were exercising 3 times/week which was still less than the prescribed frequency of 4 times/week. It is possible that the exercise stimulus was not sufficient to initiate larger changes in weight, fat-free mass and RMR in the present study.

Paragraph Number 21 Significance Our results suggest that a long-term intervention combining exercise training with a modest dietary energy restriction may help offset decreases in RMR typically seen with greater dietary energy restriction programs. When considering exercise interventions in obese or overweight adolescents, one should be aware that aerobic training, resistance training or combined aerobic and resistance training performed by our participants did not increase their RMR above baseline levels, and RMR change was therefore unlikely to contribute to weight loss. It is important to note, however, that energy expenditure from participation in structured and non-structured physical can create negative energy balance without necessarily changing RMR. Although exercise training is associated with many health benefits, our study showed that aerobic training alone, resistance training alone or their combination did not increase energy expenditure at rest.

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CONFLICT OF INTEREST

Paragraph Number 23 The authors disclose no conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Table 1. Baseline participant characteristics.

	Total Sample (N=304)	Aerobic (n=75)	Resistance (n=78)	Combined (n=75)	Control (n=76)
Males, N (%)	91 (30)	22 (29)	23 (29)	22 (29)	24 (32)
Females, N (%)	213 (70)	53 (71)	55 (71)	53 (71)	52 (68)
Age (years)	15.6 (1.4)	15.5 (1.4)	15.9 (1.5)	15.5 (1.3)	15.6 (1.3)
Weight (kg)	98.0 (16.9)	96.7 (15.1)	99.9 (17.4)	97.5 (16.3)	97.9 (18.8)
Height (cm)	167.8 (7.4)	166.8 (7.0)	168.3 (7.5)	167.5 (7.6)	168.8 (7.7)
BMI (kg/m^2)	34.6 (4.5)	34.7 (4.2)	35.1 (4.6)	34.6 (4.2)	34.1 (4.9)
Waist circumference (cm)	96.8 (11.0)	96.4 (10.1)	98.8 (11.4)	96.8 (10.5)	95.2 (11.8)
Total body fat (%)	49.5 (5.6)	49.1 (5.8)	49.9 (5.8)	50.3 (5.3)	48.6 (5.3)
Total body fat (kg)	47.6 (10.8)	47.0 (10.7)	48.3 (10.8)	48.3 (10.3)	46.6 (11.6)
Total fat-free mass (kg)	48.0 (8.4)	48.0 (7.5)	48.2 (8.9)	47.3 (8.3)	48.7 (8.9)
Resting heart rate (bpm)	71 (8.4)	71 (9)	71 (8)	72 (9)	70 (8)
Respiratory exchange ratio	0.77 (0.06)	0.77 (0.05)	0.77 (0.06)	0.77 (0.07)	0.78 (0.06)

Values are mean (standard deviation) unless otherwise stated.
Abbreviations: BMI: Body Mass Index, bpm: beats per minute.

TABLE 2. Resting metabolic rate and fat-free mass at baseline and after 6 months.

		Mean (SE)		Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
			INTENTION-TO-TREAT ANALYSIS		
RMR (kcal/day)					
Aerobic	75	1972 (38)	1990 (41)	18 (-62, 98)	
Resistance	77	2024 (37)	1992 (41)	-32 (-111, 47)	
Combined	75	2023 (38)	1995 (38)	-29 (-103, 46)	
Control	72	2075 (38)	2073 (39)	-2 (-79 , 76)	
Aerobic vs. control					20 (-91, 131)
Resistance vs. control					-30 (-140, 81)
Combined vs. aerobic					-47 (-156, 62)
Combined vs. resistance					3 (-105, 111)
Total fat-free mass (kg)					
Aerobic	74	48.2 (0.7)	48.9 (0.7)	0.7 (0.0, 1.3)*	
Resistance	75	48.3 (0.7)	49.7 (0.7)	1.4 (0.7, 2.0)***	
Combined	74	47.7 (0.7)	48.4 (0.7)	0.8 (0.1, 1.4)*	
Control	74	48.6 (0.7)	49.7 (0.7)	1.1 (0.5, 1.7)	
Aerobic vs. control					-0.4 (-1.3, 0.5)
Resistance vs. control					0.3 (-0.6, 1.2)
Combined vs. aerobic					0.1 (-0.8, 1.0)
Combined vs. resistance					-0.6 (-1.5, 0.3)

Total skeletal muscle mass (kg)					
Aerobic	74	24.9 (0.5)	25.1 (0.5)	0.2 (-0.2, 0.6)	
Resistance	75	24.8 (0.5)	25.7 (0.5)	0.9 (0.5, 1.3)***	
Combined	74	24.5 (0.5)	25.0 (0.5)	0.4 (0.0, 0.8)*	
Control	74	25.0 (0.5)	25.7 (0.5)	0.7 (0.3, 1.1)**	
					-0.4 (-1.0, 0.1)
					0.3 (-0.3, 0.8)
					0.2 (-0.4, 0.8)
					-0.5 (-1.1, 0.1)

Values are means (SE), *p<0.05, **p<0.01, ***p<0.001.
Abbreviations: RMR= Resting Metabolic Rate, kcal/day= kilocalories per day.
Note: RMR was adjusted for group, visit, group*visit, age, and gender.

FIGURE CAPTIONS

Figure 1. Changes in resting metabolic rate (RMR) in kcal/day adjusted for group, visit, group*visit, age, gender and total body weight from baseline to 6 months in aerobic, resistance, combined and control groups. Data are presented as means (SE). No significant differences were observed between groups (p>0.05).

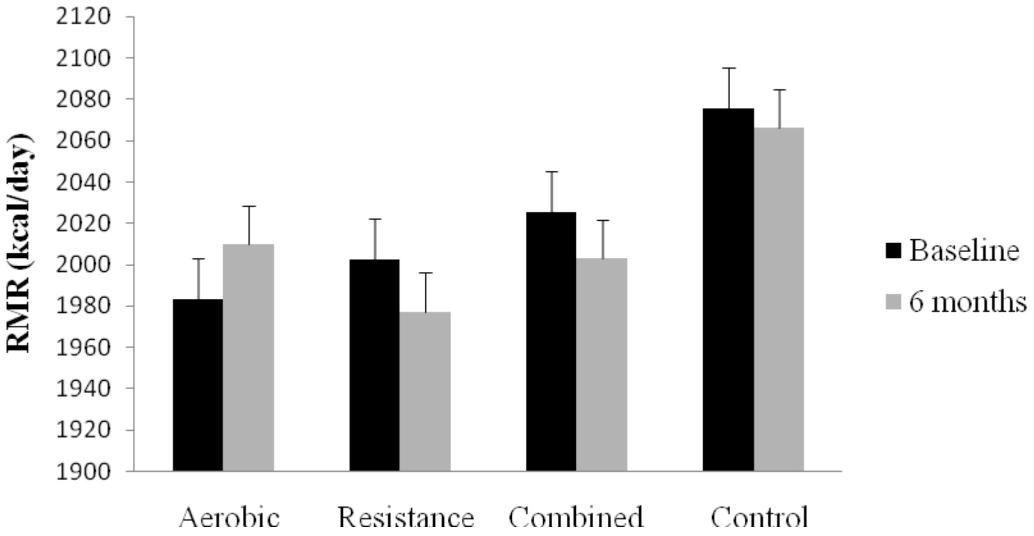
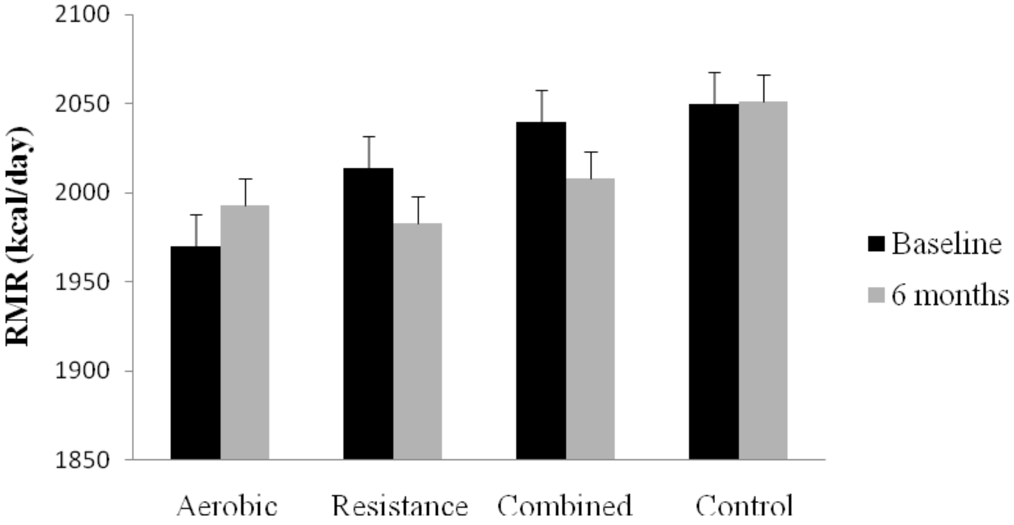


Figure 2. Changes resting metabolic rate (RMR) in kcal/day adjusted for group, visit, group*visit, age, gender and total fat-free mass from baseline to 6 months in aerobic, resistance, combined and control groups. Data are presented as means (SE). No significant differences were observed between groups (p>0.05).



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Online Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about the HEARTY trial results.

Supplement to: Exercise training and resting metabolic rate in obese adolescents: the HEARTY trial

Table of Contents for Appendix

List of investigators:
Angela S. Alberga, Denis Prud'homme, Ronald J. Sigal, Gary S. Goldfield, Stasia Hadjiyannakis, Réjeanne Gougeon, Penny Phillips, Janine Malcolm, George Wells, Steve Doucette, Jinhui Ma and Glen P. Kenny.

Table S1. Per-protocol analysis of resting metabolic rate and fat-free mass at baseline and after 6 months.

		Mean (SE)		**Mean (95% Confidence Interval)**	
Variable	**N**	**Baseline**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
		PER-PROTOCOL ANALYSIS			
RMR (kcal/day)					
Aerobic	35	1984 (52)	2006 (49)	21 (-76, 118)	
Resistance	23	2155 (65)	2172 (61)	18 (-102, 138)	
Combined	29	2033 (58)	1998 (53)	-35 (-138, 69)	
Control	72	2089 (36)	2089 (38)	0 (-76, 76)	
Aerobic vs. control					21 (-102, 145)
Resistance vs. control					18 (-124, 160)
Combined vs. aerobic					-56 (-198, 86)
Combined vs. resistance					-52 (-211, 106)
RMR (kcal/day) **adjusted for body weight**					
Aerobic	35	2008 (41)	2026 (42)	18 (-80, 115)	
Resistance	23	2100 (51)	2121 (52)	21 (-99, 141)	
Combined	29	2043 (46)	2009 (44)	-35 (-138, 69)	
Control	72	2094 (29)	2085 (33)	-9 (-84, 66)	
Aerobic vs. control					26 (-96, 149)
Resistance vs. control					30 (-112, 171)
Combined vs. aerobic					-52 (-194, 90)
Combined vs. resistance					-55 (-214, 103)

RMR (kcal/day)$_{\text{adjusted for fat-free mass}}$					
Aerobic	35	1993 (44)	2011 (44)	19 (-78, 115)	
Resistance	23	2122 (55)	2138 (55)	16 (-103, 135)	
Combined	29	2066 (49)	2032 (47)	-35 (-137, 68)	
Control	70	2072 (31)	2074 (34)	2 (-73, 77)	
Aerobic vs. control					17 (-105, 139)
Resistance vs. control					14 (-127, 155)
Combined vs. aerobic					-53 (-194, 88)
Combined vs. resistance					-50 (-208, 107)
Total fat-free mass (kg)					
Aerobic	35	48.4 (1.1)	49.2 (1.0)	0.8 (-0.2, 1.7)	
Resistance	23	50.3 (1.3)	52.3 (1.2)	2.0 (0.9, 3.2)**	
Combined	29	47.0 (1.2)	48.2 (1.1)	1.2 (0.2, 2.2)*	
Control	74	49.1 (0.7)	50.2 (0.7)	1.1 (0.4, 1.8)**	
Aerobic vs. control					-0.4 (-1.5, 0.8)
Resistance vs. control					0.9 (-0.5, 2.2)
Combined vs. aerobic					0.5 (-0.9, 1.8)
Combined vs. resistance					-0.8 (-2.3, 0.7)
Total skeletal muscle mass (kg)					
Aerobic	35	24.9 (0.7)	25.2 (0.7)	0.3 (-0.3, 0.8)	
Resistance	23	26.4 (0.9)	27.5 (0.8)	1.2 (0.5, 1.9)**	
Combined	29	24.0 (0.8)	24.7 (0.7)	0.6 (0.0, 1.3)*	
Control	74	25.3 (0.5)	26.0 (0.5)	0.7 (0.2, 1.1)**	
Aerobic vs. control					-0.4 (-1.1, 0.3)
Resistance vs. control					0.5 (-0.3, 1.3)
Combined vs. aerobic					0.4 (-0.5, 1.2)
Combined vs. resistance					-0.5 (-1.5, 0.4)

Values are means (SE), *p<0.05, **p<0.01, ***p<0.001.
Abbreviations: BMI= Body Mass Index, kcal= kilocalories, RMR= resting metabolic rate.

Note: All RMR results were adjusted for group, visit, group*visit, age, and gender with additional adjustments for body weight and fat-free mass as indicated. Per-protocol analysis included only participants with ≥ 70% compliance from baseline to the end of the intervention period.

Table S2. Intention-to-treat and per-protocol analyses of body composition and resting metabolic rate at baseline and after 6 months in males only.

		Mean (SE)		Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
		INTENTION TO TREAT ANALYSIS			
RMR (kcal/day)					
Aerobic	22	2217 (71)	2269 (67)	52 (-85, 189)	
Resistance	22	2461 (72)	2342 (65)	-119 (-253, 15)	
Combined	22	2327 (72)	2296 (60)	-31 (-156, 93)	
Control	22	2434 (71)	2359 (64)	-74 (-213, 64)	
Aerobic vs. control					126 (-69, 3222)
Resistance vs. control					-44 (-237, 148)
Combined vs. aerobic					-83 (-268, 102)
Combined vs. resistance					88 (-95, 270)
RMR (kcal/day) **adjusted for body weight**					
Aerobic	22	2239 (61)	2297 (61)	58 (-79, 195)	
Resistance	22	2440 (61)	2328 (59)	-112 (-246, 22)	
Combined	22	2351 (61)	2321 (54)	-30 (-155, 94)	
Control	22	2394 (61)	2319 (59)	-75 (-212, 63)	
Aerobic vs. control					133 (-61, 327)
Resistance vs. control					-38 (-229, 154)
Combined vs. aerobic					-89 (-274, 96)
Combined vs. resistance					82 (-101, 265)

RMR (kcal/day) **adjusted for fat-free mass**					
Aerobic	22	2230 (65)	2287 (66)	57 (-81, 194)	
Resistance	21	2425 (67)	2318 (64)	-107 (-242, 28)	
Combined	21	2353 (67)	2306 (60)	-47 (-174, 80)	
Control	21	2416 (66)	2343 (64)	-73 (-212, 66)	
Aerobic vs. control					130 (-66, 325)
Resistance vs. control					-34 (-228, 159)
Combined vs. aerobic					-104 (-291, 83)
Combined vs. resistance					60 (-125, 246)
Total fat-free mass (kg)					
Aerobic	22	55.7 (1.6)	57.7 (1.4)	2.0 (0.3, 3.6)*	
Resistance	22	57.5 (1.6)	59.5 (1.4)	2.1 (0.5, 3.6)*	
Combined	21	55.6 (1.6)	57.4 (1.4)	1.8 (0.2, 3.4)*	
Control	23	57.9 (1.5)	60.0 (1.4)	2.0 (0.4, 3.6)*	
Aerobic vs. control					-0.1 (-2.4, 2.3)
Resistance vs. control					0.0 (-2.2, 2.3)
Combined vs. aerobic					-0.2 (-2.5, 2.2)
Combined vs. resistance					-0.3 (-2.5, 2.0)
Total skeletal muscle (kg)					
Aerobic	22	29.6 (1.1)	30.6 (1.0)	1.0 (-0.1, 2.0)	
Resistance	22	30.1 (1.1)	31.6 (0.9)	1.5 (0.5, 2.4)**	
Combined	21	29.2 (1.1)	30.5 (1.0)	1.2 (0.3, 2.2)*	
Control	23	30.9 (1.0)	32.3 (0.9)	1.3 (0.4, 2.3)**	
Aerobic vs. control					-0.4 (-1.8, 1.1)
Resistance vs. control					0.2 (-1.2 to 1.5)
Combined vs. aerobic					0.3 (-1.1 to 1.7)
Combined vs. resistance					-0.3 (-1.6 to 1.1)

PER-PROTOCOL ANALYSIS					
RMR (kcal/day)					
Aerobic	12	2277 (90)	2287 (84)	10 (-154, 175)	
Resistance	7	2547 (117)	2481 (116)	-66 (-294, 162)	
Combined	13	2336 (88)	2306 (82)	-30 (-188, 128)	
Control	22	2427 (66)	2358 (69)	-69 (-211, 74)	
Aerobic vs. control					79 (-138, 296)
Resistance vs. control					3 (-266, 272)
Combined vs. aerobic					-41 (-269, 187)
Combined vs. resistance					36 (-242, 313)
RMR (kcal/day) adjusted for body weight					
Aerobic	12	2309 (76)	2319 (74)	10 (-156, 177)	
Resistance	7	2490 (100)	2435 (103)	-55 (-285, 175)	
Combined	13	2362 (74)	2332 (72)	-30 (-190, 129)	
Control	22	2404 (56)	2333 (63)	-71 (-212, 70)	
Aerobic vs. control					82 (-136, 299)
Resistance vs. control					16 (-254, 286)
Combined vs. aerobic					-41 (-271, 190)
Combined vs. resistance					25 (-255, 305)
RMR (kcal/day) adjusted for fat-free mass					
Aerobic	12	2278 (84)	2288 (81)	10 (-155, 176)	
Resistance	7	2542 (109)	2477 (113)	-66 (-295, 164)	
Combined	13	2354 (82)	2324 (80)	-30 (-189, 128)	
Control	21	2418 (63)	2349 (68)	-69 (-213, 74)	
Aerobic vs. control					80 (-139, 298)
Resistance vs. control					4 (-267, 274)
Combined vs. aerobic					-41 (-270, 188)
Combined vs. resistance					35 (-244, 314)

Total fat-free mass (kg)					
Aerobic	12	56.6 (2.0)	58.8 (1.8)	2.2 (-0.1, 4.5)	
Resistance	7	56.8 (2.7)	60.7 (2.3)	3.9 (0.8, 6.9)	
Combined	13	54.9 (2.0)	56.9 (1.7)	2.0 (-0.2 to 4.2)	
Control	23	57.5 (1.5)	59.5 (1.3)	2.0 (0.2 to 3.9)	
Aerobic vs. control					0.2 (-2.8, 3.1)
Resistance vs. control					1.8 (-1.7, 5.4)
Combined vs. aerobic					-0.2 (-3.4, 3.0)
Combined vs. resistance					-1.9 (-5.6, 1.9)
Total skeletal muscle (kg)					
Aerobic	12	30.3 (1.4)	31.2 (1.1)	1.0 (-0.4 to 2.3)	
Resistance	7	30.0 (1.8)	32.2 (1.5)	2.1 (0.3 to 3.9)	
Combined	13	28.6 (1.3)	29.8 (1.1)	1.2 (-0.1 to 2.5)	
Control	23	30.6 (1.0)	32.0 (0.8)	1.3 (0.2 to 2.4)	
Aerobic vs. control					-0.4 (-2.1, 1.4)
Resistance vs. control					0.8 (-1.3, 2.9)
Combined vs. aerobic					0.3 (-1.7, 2.2)
Combined vs. resistance					-0.9 (-3.2, 1.3)

Values are means (SE), *p<0.05, **p<0.01, ***p<0.001.
Abbreviations: BMI= Body Mass Index, kcal= kilocalories, RMR= resting metabolic rate.
Note: RMR was adjusted for group, visit, group*visit, age, and gender with additional adjustments for body weight and fat-free mass as indicated. Intention-to-treat analysis included all male participants regardless of compliance. Per-protocol analysis included only male participants with ≥ 70% compliance from baseline to the end of the intervention period.

Table S3. Intention-to-treat and per-protocol analyses of body composition and resting metabolic rate at baseline and after 6 months in females only.

		Mean (SE)		Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
		INTENTION-TO-TREAT ANALYSIS			
RMR (kcal/day)					
Aerobic	53	1857 (44)	1863 (52)	6 (-94, 106)	
Resistance	55	1831 (43)	1833 (52)	2 (-97, 102)	
Combined	53	1884 (44)	1859 (50)	-25 (-120, 69)	
Control	50	1914 (45)	1942 (49)	28 (-67, 123)	
Aerobic vs. control					-22 (-159, 116)
Resistance vs. control					-26 (-163, 112)
Combined vs. aerobic					-31 (-169, 106)
Combined vs. resistance					-28 (-165, 110)
RMR (kcal/day) **adjusted for body weight**					
Aerobic	53	1863 (33)	1881 (44)	18 (-80, 116)	
Resistance	55	1809 (33)	1821 (44)	12 (-85, 109)	
Combined	53	1872 (33)	1854 (41)	-18 (-111, 75)	
Control	50	1939 (34)	1957 (41)	18 (-75, 111)	
Aerobic vs. control					0 (-135, 135)
Resistance vs. control					-6 (-140, 129)
Combined vs. aerobic					-36 (-170, 99)
Combined vs. resistance					-30 (-164, 105)

RMR (kcal/day) **adjusted for fat-free mass**					
Aerobic	52	1846 (36)	1859 (44)	12 (-84, 109)	
Resistance	53	1838 (36)	1846 (44)	8 (-89, 104)	
Combined	53	1897 (35)	1870 (41)	-26 (-118, 66)	
Control	49	1893 (37)	1922 (41)	29 (-63, 122)	
Aerobic vs. control					-17 (-151, 117)
Resistance vs. control					-22 (-155, 112)
Combined vs. aerobic					-39 (-172, 95)
Combined vs. resistance					-34 (-167, 100)
Total fat-free mass (kg)					
Aerobic	52	44.7 (0.8)	44.9 (0.8)	0.2 (-0.4, 0.7)	
Resistance	53	44.3 (0.8)	45.2 (0.8)	0.9 (0.3, 1.4)**	
Combined	53	44.1 (0.7)	44.4 (0.8)	0.3 (-0.2, 0.9)	
Control	51	44.5 (0.8)	45.1 (0.8)	0.6 (0.1 to 1.1)*	
Aerobic vs. control					-0.4 (-1.2, 0.3)
Resistance vs. control					0.3 (-0.4, 1.1)
Combined vs. aerobic					0.2 (-0.6, 0.9)
Combined vs. resistance					-0.6 (-1.3, 0.2)
Total skeletal muscle (kg)					
Aerobic	52	22.7 (0.5)	22.6 (0.5)	-0.1 (-0.4 to 0.3)	
Resistance	53	22.4 (0.5)	23.0 (0.5)	0.6 (0.2 to 0.9)**	
Combined	53	22.5 (0.5)	22.5 (0.5)	0.0 (-0.3 to 0.4)	
Control	51	22.4 (0.5)	22.6 (0.5)	0.3 (-0.1 to 0.6)	
Aerobic vs. control					-0.3 (-0.8 to 0.1)
Resistance vs. control					0.3 (-0.2 to 0.8)
Combined vs. aerobic					0.1 (-0.4 to 0.6)
Combined vs. resistance					-0.5 (-1.0 to 0)*

PER-PROTOCOL ANALYSIS					
RMR (kcal/day)					
Aerobic	23	1829 (66)	1857 (63)	28 (-96, 151)	
Resistance	16	1955 (79)	2008 (73)	53 (-91, 197)	
Combined	16	1876 (79)	1838 (71)	-38 (-179, 103)	
Control	50	1913 (44)	1942 (46)	29 (-63, 121)	
Aerobic vs. control					-1 (-155, 153)
Resistance vs. control					24 (-147, 195)
Combined vs. aerobic					-66 (-253, 122)
Combined vs. resistance					-91 (-292, 111)
RMR (kcal/day) adjusted for body weight					
Aerobic	23	1852 (50)	1874 (50)	21 (-101, 144)	
Resistance	16	1899 (60)	1952 (58)	53 (-90, 197)	
Combined	16	1853 (59)	1815 (56)	-38 (-179, 103)	
Control	50	1938 (34)	1956 (38)	18 (-72, 108)	
Aerobic vs. control					4 (-148, 155)
Resistance vs. control					36 (-134, 205)
Combined vs. aerobic					-59 (-246, 127)
Combined vs. resistance					-91 (-292, 110)
RMR (kcal/day) adjusted for fat-free mass					
Aerobic	23	1855 (50)	1879 (48)	24 (-98, 146)	
Resistance	16	1892 (61)	1944 (56)	52 (-91, 194)	
Combined	16	1903 (60)	1866 (54)	-38 (-178, 102)	
Control	49	1903 (34)	1933 (36)	30 (-59, 119)	
Aerobic vs. control					-6 (-157, 145)
Resistance vs. control					22 (-147, 190)
Combined vs. aerobic					-62 (-248, 124)
Combined vs. resistance					-90 (-290, 110)

Total fat-free mass (kg)					
Aerobic	23	44.0 (1.2)	44.0 (1.2)	0.0 (-0.6, 0.7)	
Resistance	16	46.6 (1.4)	47.9 (1.4)	1.2 (0.4, 2.0)**	
Combined	16	43.9 (1.4)	44.5 (1.4)	0.6 (-0.2, 1.3)	
Control	51	44.5 (0.8)	45.1 (0.8)	0.6 (0.1 to 1.1)*	
Aerobic vs. control					-0.6 (-1.4, 0.3)
Resistance vs. control					0.6 (-0.3, 1.6)
Combined vs. aerobic					0.6 (-0.5, 1.6)
Combined vs. resistance					-0.6 (-1.8, 0.5)
Total skeletal muscle (kg)					
Aerobic	23	22.0 (0.8)	21.9 (0.8)	-0.1 (-0.5, 0.4)	
Resistance	16	24.3 (0.9)	25.0 (0.9)	0.7 (0.2, 1.3)**	
Combined	16	22.4 (0.9)	22.6 (0.9)	0.2 (-0.4, 0.7)	
Control	51	22.3 (0.5)	22.6 (0.5)	0.3 (-0.1, 0.6)	
Aerobic vs. control					-0.4 (-0.9, 0.2)
Resistance vs. control					0.5 (-0.2, 1.1)
Combined vs. aerobic					0.3 (-0.4, 1.0)
Combined vs. resistance					-0.6 (-1.3 to 0.2)

Values are means (SE), *p<0.05, **p<0.01, ***p<0.001.

Abbreviations: BMI= Body Mass Index, kcal= kilocalories, RMR= resting metabolic rate.

Note: RMR was adjusted for group, visit, group*visit, age, and gender with additional adjustments for body weight and fat-free mass as indicated. Intention-to-treat analysis included all female participants regardless of compliance. Per-protocol analysis included only female participants with ≥ 70% compliance from baseline to the end of the intervention period.

MANUSCRIPT 8: Effects of aerobic training, resistance training or both on cardiorespiratory and musculoskeletal fitness in obese adolescents: the HEARTY trial

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Effects of aerobic training, resistance training or both on cardiorespiratory and musculoskeletal fitness in obese adolescents: the HEARTY trial

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ABSTRACT

PURPOSE: To examine the effects of aerobic, resistance, and combined exercise training on cardiorespiratory and musculoskeletal fitness in post-pubertal overweight and obese adolescents aged 14–18 years. **METHODS:** After a 4-week supervised moderate-intensity exercise run-in, 304 overweight and obese adolescents (body mass index ≥85th percentile) were randomized to 4 groups for 22 weeks of Aerobic training, Resistance training, Combined training, or a non-exercising Control. All participants received dietary counseling with a maximum daily energy deficit of 250 kcal. Cardiorespiratory fitness [peak oxygen consumption (VO_2peak)] was measured by indirect calorimetry using a graded exercise test on a treadmill. Musculoskeletal fitness was measured using the Canadian Physical Activity Fitness and Lifestyle Appraisal tests (hand grip, push-ups, partial curl-ups, sit and reach and vertical jump). Muscular strength was assessed by the 8-repetition maximum test on the bench press, seated row and leg press machines. **RESULTS:** Increases in VO_{2peak} in Aerobic (30.6 ± 0.6 to 33.4 ± 0.7 mLO_2/kg/min) were greater than in controls (30.6 ± 0.5 to 30.9 ± 0.7 mLO_2/kg/min) ($p=0.002$). The number of partial curl-ups increased in aerobic (19 ± 1 to 23 ± 1) compared to controls (19 ± 1 to 20 ± 1) ($p=0.015$). Increases in muscular strength and number of push-ups were greatest in Resistance versus control and Combined versus Aerobic ($p<0.05$). **CONCLUSION:** Aerobic training had the strongest effect on aerobic fitness, while combined training improved both muscular strength and endurance more than aerobic training alone in overweight and obese adolescents.

Keywords: cardiorespiratory fitness, strength, endurance, obese adolescents, exercise

INTRODUCTION

Physical activity levels and cardiorespiratory and musculoskeletal fitness of Canadian children and youth have declined substantially from 1981 to 2007–2009 (Craig, Shields, Leblanc, & Tremblay, 2012; Tremblay, 2010). Adolescents are at particularly high risk of adverse health outcomes associated with physical inactivity given that the most drastic declines in physical activity levels are observed in adolescence (Kimm, et al., 2002; Sallis, 2000) and 80% of obese adolescents become obese adults (Daniels, et al., 2005). Cardiorespiratory and musculoskeletal fitness are independently associated with metabolic risk in adolescents (Artero, et al., 2011) and it is well known that greater fitness is associated with better health status (Warburton, Gledhill, & Quinney, 2001) and lower mortality rates (Fitzgerald, et al., 2004; Goel, et al., 2011) in adults. Furthermore, lower cardiorespiratory fitness is associated with higher mortality regardless of the level of adiposity (McAuley, et al., 2012).

Improvements in cardiorespiratory fitness following moderate to high intensity [55-80% of peak oxygen consumption (VO_2peak)] aerobic training ≥40 minutes/session, 2-5 sessions/week in obese adolescents are well-documented (Ben Ounis, et al., 2010; Gutin, et al., 2002; K. J. Lee, Shin, Lee, Jun, & Song, 2010; S. Lee, et al., 2012; Tjonna, et al., 2009). However, only two well-controlled intervention studies have evaluated the effects of aerobic training on muscular strength in obese adolescents, and they showed inconsistent results (S. Lee, et al., 2012; Tjonna, et al., 2009). On the other hand, multiple studies demonstrated that progressive moderate-intensity higher-volume (higher number of sets) resistance training incorporating single and multi-joint whole-body exercises 2-3 sessions/week increased lean body mass (S. Lee, et al., 2012; Shaibi, et al., 2006; Suh, et al., 2011) and muscular strength (Davis, Tung, et al., 2009; S. Lee, et al., 2012; Shaibi, et al., 2006) in obese adolescents. In recent years, resistance training has garnered more attention as an alternate exercise modality to improve motivation and adherence to exercise training in obese youth (Schranz, Tomkinson, & Olds, 2013). However, well-controlled studies evaluating the effects of resistance training on cardiorespiratory fitness and muscular endurance, flexibility and power have received limited attention and warrant further study.

Taken together, the combined effects of aerobic and resistance training could result in superior improvements in cardiorespiratory and musculoskeletal fitness compared to either modality alone. To our knowledge, no studies have compared the effects of combined training to aerobic and resistance exercise alone in overweight or obese adolescents and no studies have utilized a standardized battery of tests to assess the complete spectrum of musculoskeletal fitness (muscular strength, endurance, power and flexibility) in this population. Filling these knowledge gaps could have important clinical implications for program design and exercise recommendations for adolescents with excess body weight.

Thus, the present study aims to examine the effects of 6 months of aerobic training, resistance training and their combination on cardiorespiratory fitness as assessed by VO_{2peak} and musculoskeletal fitness (muscular strength, endurance, power and flexibility) in overweight and obese adolescents. We hypothesized *a priori* that the combined training group would improve both cardiorespiratory and musculoskeletal fitness compared to either exercise training modality alone.

METHODS

Participants

This paper investigates the effects of exercise training on cardiorespiratory and musculoskeletal fitness as secondary outcomes of the HEARTY (Healthy Eating Aerobic and Resistance Training in Youth) trial which has been described in detail elsewhere (Alberga, et al., 2012).

After a 4-week run-in to assess exercise adherence, 304 post-pubertal overweight and obese adolescents (age 14-18 years, body mass index (BMI) >95th percentile for age and sex, or >85th percentile plus a diabetes risk factor) were randomized into 4 groups for 22 weeks (5 months): 1. aerobic training (Aerobic, n=75), 2. resistance training (Resistance, n=78), 3. combined aerobic and resistance training (Combined, n=75) or 4. non-exercising control (Control, n=76).

Intervention

Details of the diet counseling and exercise training program were published previously (Alberga, et al., 2012). Briefly, participants in all 4 groups received dietary counselling designed to promote healthy eating with a maximum daily energy deficit of 250 kcal by a registered dietitian. During the 4-week run-in, participants were asked to exercise 4 sessions per week at an aerobic intensity of 65% of their measured maximum heart rate (HR_{max}) for 15-30 minutes per session and to complete 1-3 sets of 15 reps at 15 Repetitions Maximum (RM), the maximum that could be moved 15 times through the full range of motion while maintaining proper form for the resistance training component. Participants who attended at least 13 of the 16 exercise sessions during run-in were then randomized to one of 4 groups for 22 weeks (weeks 5-26). Participants randomized to the three exercise groups exercised 4 sessions per week at local fitness centers in the Ottawa/Gatineau, Canada, region. They were supervised by personal trainers weekly for 8 weeks after randomization, then every 2 weeks. Participants in the aerobic training group exercised on a treadmill, bike and/or elliptical at an intensity progressing from 70% HR_{max} for 20 min per session to 85% of HR_{max} for 40 min per session. The resistance training group performed 7 whole-body exercises on resistance machines progressing from 15 repetitions at 15 RM to 6 repetitions at 6RM performed over 20-40 minutes per session. The combined training group performed both the aerobic and the resistance components during each exercise session for a maximum of 4 sessions per week for 22 weeks. The participants in the control group were asked to revert back to their baseline activity levels and were offered the exercise program of their choice after the intervention program. The personal trainers monitored attendance and adherence was calculated as the total number of exercise sessions the participant attended divided by the total number of sessions prescribed from baseline to the end of the intervention.

Cardiorespiratory fitness

Cardiorespiratory fitness was determined by VO_2peak at baseline and at 6-months measured during a graded exercise test following the modified Balke and Ware incremental treadmill test (Balke, 1963). The treadmill speed was predetermined during a practice session and was held constant throughout the entire test. Three different continuous ramp protocols (slow: <3.0, average: 3.0, fast: 3.5 miles/hour) were used based on the participant's ability, and for each individual the same ramp protocol was used at baseline and 6 months. The test began with a 1-minute warm-up period during which the participant walked at 2 miles per hour at a 0% incline. The walking speed was increased to the predetermined pace and remained the same throughout the entire duration of test. The treadmill grade was progressively increased by 2% every minute until the participants reached volitional exhaustion. Data was collected in 10-second averaging intervals for the duration of the stress test. Oxygen consumption was measured by indirect calorimetry using an automated metabolic system (MOXUS Modular Metabolic System, AEI Technologies Naperville, IL, USA).

Tests were terminated when the participants expressed desire to stop at their maximal exertion. The highest relative rate of oxygen consumption [VO_2 (mLO_2/kg/min)] achieved was considered to be the VO_{2peak} for the participant. Treadmill time was defined as the time from the start of the test until the time where the participant reached $VO_{2peak.}$

Muscular strength

An 8-RM test (determining the maximum weight that could be lifted eight times for the specific resistance exercise while maintaining proper exercise movement form) was performed on the bench press, seated row and leg press machines at 0, 3 and 6 months. The test was administered in the gym by a personal trainer.

Musculoskeletal fitness

The five musculoskeletal fitness tests were conducted at baseline and at 6 months to assess muscular strength, endurance, power and flexibility according to established testing protocols from the Canadian Physical Activity, Fitness & Lifestyle Approach (CPAFLA) designed by the Canadian Society for Exercise Physiology (CSEP) (*Canadian Society for Exercise Physiology. The Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA). Third Edition*, 2003). Briefly, the CPAFLA tests were conducted in consecutive order: handgrip test, push-ups, sit and reach, partial curl-ups and vertical jump. Arm muscular strength was assessed on a hand-grip dynamometer (Baseline Hydraulic Hand Dynamometer, #OC-3054-02, OrthoCanada). Both hands of participants were assessed twice and the maximum score of each hand was combined to obtain a total arm muscular strength score in kilograms. Upper body muscular endurance was assessed by the push-ups test, asking participants to complete as many consecutive push-ups as possible while maintaining proper technique (no time limit). The push-ups test technique was different according to sex; males used their toes, and females used their knees, as the pivot point. The sit and reach test was used as an indicator of flexibility and provided a measure of the range of motion in the hips and lower back. The participant's feet were placed against the backboard of the sit and reach flexometer (Flex-Tester Sit and Reach Flexibility Test Box) at the 23-cm mark, and the participant was advised to stretch out his/her arms and hands in the direction of their feet while pushing a sliding marker forward along the horizontal scale on which the maximum distance reached was recorded in centimeters. Muscular endurance of the abdominal and hip flexor muscles was assessed using the partial curl-up test. The participant was asked to perform as many partial curl-ups as possible over a 1-minute period at a set cadence of 50 beats per minute for a maximum of 25 repetitions. A vertical jump test was then performed to assess leg muscular power. Participants performed a vertical jump from a semi-squatting position to a peak jump height. Leg muscular power was then determined using the difference between peak vertical jump height and the stand-and-reach-height using the following formula by Sayers et al. (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999):

Leg Power (W) = [60.7 x jump height (cm)] + [45.3 x body mass (kg)] – 2055……………………… (1)

Statistical Analysis

The primary analysis was intention-to-treat, including all participants even if they dropped out. Linear mixed-effects modeling was used with repeated measures over time with cardiorespiratory fitness (VO_{2peak}, treadmill time) and musculoskeletal (leg press, bench press, seated row, grip strength, push-ups, sit-and-reach, partial curl-ups, leg power) as the dependent variables and effects for time (0, 3 and 6 months), study group (Aerobic, Resistance, Combined, Control), and time-by-group interaction with age and sex as covariates and an unstructured covariance matrix. Within the mixed models, we estimated 95% confidence intervals (CI) and p-values for the 4 prespecified intergroup comparisons (Aerobic vs. Control, Resistance vs. Control, Combined vs. Aerobic and Combined vs. Resistance) and for changes in fitness outcomes within each group over time. In addition to the primary intention-to-treat analyses, we conducted per-protocol analyses including only those participants who completed at least 70% of prescribed exercise sessions (≥2.8 sessions/week) and all follow-up measures following the same procedures as in the intention-to-treat analyses. All analyses were performed using the statistical software package SAS, version #9.2 (SAS Institute, Cary, North Carolina).

Results

Descriptive characteristics of the sample are presented in Table 1. Participants were 70% female, 72% Caucasian, BMI of 34.6 ± 4.5 kg/m^2, aged 15.6 ± 1.4 years old. From baseline to 26 weeks, there were no significant differences in adherence rates between exercise groups. The median exercise training adherence was 62% (interquartile range, 36% to 81%) in the Aerobic group, 56% (interquartile range, 37% to 75%) in the Resistance group and 64% (interquartile range, 39% to 75%) in the Combined group.

Cardiorespiratory fitness

The cardiorespiratory fitness results are presented in Table 2. Treadmill time increased in all 3 exercise groups in both intention-to-treat and per-protocol analyses. The increases in VO_{2peak} in Aerobic were greater than in Controls. Although the combined group increased VO_{2peak} and treadmill time from baseline to post-intervention, these changes were not significantly different from the other groups. Treadmill time increased in the aerobic group vs. control. Examination of per protocol analyses based on participants adhering to ≥70% of prescribed sessions showed the same pattern of results as that reported above for the intention to treat analyses.

Musculoskeletal fitness

Muscular strength by 8-RM

Musculoskeletal fitness test results are presented in Table 3. The aerobic group and the resistance groups showed greater increases in leg press compared to control. Furthermore, the combined group showed greater increases in leg press, bench press and seated row compared to the aerobic group. The resistance group showed greater increases in bench press compared to the control group. However, the changes in muscular strength in the combined group were not significantly different from the changes from the resistance exercise group on the leg press, bench press or seated row machines. Only in the most adherent participants (results from per-protocol analyses of participants with ≥70% compliance shown in Table 3) were the improvements in leg press in the resistance exercise group greater than those in the combined exercise group.

Canadian Physical Activity, Fitness & Lifestyle Appraisal (CPAFLA) tests

Results from the CPAFLA tests are also presented in Table 3. The number of push-ups increased from baseline to post-intervention in all four groups and they improved more in Resistance compared to Control and in Combined compared to Aerobic. Partial curl-ups increased in Aerobic, Resistance and Combined groups but only the increases in Aerobic were different from Control. Grip strength increased from baseline to post-intervention in all four groups but there were no significant between-group changes in both intention-to-treat and per-protocol analyses. There were no significant within-group or between-group differences in sit-and-reach and leg power for both the intention to treat and per protocol analyses.

DISCUSSION

We found that although the aerobic and the combined groups increased VO_{2peak}, the improvements in cardiorespiratory fitness were greater in the aerobic group only compared to controls.

Aerobic exercise training alone increased abdominal muscular endurance (partial curl-ups), while resistance training alone increased upper and lower body muscular strength and endurance as measured by the bench press, leg press and push-up tests. The Combined group improved both VO_{2peak} and musculoskeletal fitness (leg press, bench press, seated row, partial curl-ups and push-ups) in overweight and obese adolescents.

Cardiorespiratory fitness

Although VO_{2peak} increased in the aerobic and the combined aerobic and resistance exercise training groups from baseline to post-intervention, both intention-to-treat and per-protocol analyses showed that only the increases in the aerobic group were significantly greater than in the control group. Treadmill time, another indicator of cardiorespiratory fitness, also increased significantly in all three exercise training groups, however, only the increases in the aerobic group were significantly different from control. Our results are consistent with other studies in obese adolescents that have shown increases in cardiorespiratory fitness following an exercise intervention including an aerobic exercise training component (Ben Ounis, et al., 2010; Gutin, et al., 2002; K. J. Lee, et al., 2010; S. Lee, et al., 2012; Tjonna, et al., 2009). In our Diabetes Aerobic and Resistance Exercise Trial, which employed a similar design to the current HEARTY trial in overweight and obese adults with type 2 diabetes, the findings were similar: aerobic and combined exercise each increased aerobic fitness, but the aerobic-only intervention did so to a slightly greater extent (Larose, et al., 2010). The findings of the HEARTY trial support that moderate to high intensity aerobic or combined aerobic and resistance exercise training for at least 3 sessions per week improves cardiorespiratory fitness in overweight and obese adolescents.

Resistance exercise training alone, however, did not increase cardiorespiratory fitness. This finding differs from the previously-mentioned trial by Lee et al (S. Lee, et al., 2012) which showed increases in

$\dot{V}O_{2peak}$ in both the aerobic (+9.1 ± 0.9 mLO_2/kg/min) and the resistance (+7.7 ± 0.9 mLO_2/kg/min) exercise training groups compared with the control group (-0.04 ± 1.1 mLO_2/kg/min; $p<0.0001$). The participants in Lee et al.'s study were randomized to an aerobic training group (40-60 min at 50-75% of VO_{2peak}), resistance training group (10 whole-body exercises 8-12 repetitions of 60% 1-RM to fatigue for 60 min/ session) 3 times per week or a non-exercising control for 3 months. All their participants were also asked to follow a weight maintenance diet (55–60% carbohydrate, 15–20% protein, and 20–25% fat) during the intervention. Although the study by Lee et al. (S. Lee, et al., 2012) and the HEARTY trial employed a similar exercise training program, the participants in Lee et al.'s study showed greater exercise adherence in both the aerobic and resistance exercise groups (>99%, perhaps in part because participants received some compensation), and this greater adherence might account for larger physiological changes. The Lee et al trial (12) incorporated a longer aerobic training duration per session than our trial (40-60 min compared to 20-40min) and their participants were males only (compared to our sample consisting of 70% females) and approximately 50% were of black race (compared with 10% in our trial). These differences in sample characteristics may also explain, in part, the discrepant findings. Our results are more consistent with those of Gutin et al.(Gutin, et al., 2002), who offered aerobic exercise training 5 times per week but showed smaller increases of +1.72 mLO_2/kg/min in VO_{2peak} from baseline to 8 months of moderate to high intensity aerobic training (55-80% VO_{2peak}) in obese adolescents aged 13-16 years old who maintained ≥40% exercise sessions adherence (≥ 2 sessions per week). Gutin et al. reported 51% (5-92) adherence for the moderate intensity aerobic training group and 56% (16-83) for the high intensity aerobic training group although their adherence rates were not significantly different between groups.

Musculoskeletal fitness

The present study showed that all three types of exercise training (aerobic, resistance and their combination) increased lower body muscular strength (leg press). These results are in agreement with one aerobic exercise interval training study in obese adolescents (Tjonna, et al., 2009) but differ from the results reported by Lee et al. showing no significant changes in chest or leg strength following aerobic exercise training compared with the non-exercising control group (S. Lee, et al., 2012). The present study is the first randomized controlled trial that compared the effects of aerobic, resistance or combined aerobic and resistance exercise training on a comprehensive battery of whole-body musculoskeletal fitness tests in a large sample of overweight and obese adolescents. We showed that the greatest increase in lower body muscular strength (leg press) was observed in the resistance exercise training group. The increase in the combined training group was significantly less in our most adherent participants, even though the resistance exercise prescription was the same in these two groups. Although the gains in total skeletal muscle mass appeared greater from baseline to post-intervention in the resistance group (+1.2 kg, p=0.001) and in the combined group (+0.6 kg, p=0.045), these changes were not significantly different between groups of our most adherent sample. Conversely, the results of the vertical jump test that was used to assess leg power did not change following exercise training in any group. The vertical jump test requires vertical propulsion of one's own body weight and thus, may not be the best metric to use in overweight or obese adolescents (Deforche, et al., 2003). Perhaps their body weight may have limited their ability to perform and improve their scores on this test if they did not show large concomitant decreases in body weight following the intervention.

We also showed increases in upper body muscular strength (bench press) and endurance (push-ups) in the resistance and the combined training groups. Improvements in muscular strength have been observed in previous studies with obese Latino adolescents with resistance exercise training (Davis, Kelly, et al., 2009; Shaibi, et al., 2006) and combined aerobic and resistance exercise training (Davis, et al., 2011; Davis, Tung, et al., 2009). Increases in strength are usually explained by improved neural adaptation (increased motor neuron activation and motor unit synchronization, especially early in training) (Sale, 1988) and muscle hypertrophy (Jones & Rutherford, 1987; Narici, Roi, Landoni, Minetti, & Cerretelli, 1989). Among participants with good adherence we observed regional changes in body composition that may help explain the improvements in musculoskeletal fitness. Arm skeletal muscle (0.49 kg), upper body skeletal muscle (0.57 kg) and total skeletal muscle mass (1.2 kg) increased from baseline to post-intervention in the resistance training group and in the combined training group (0.20, 0.36 and 0.6 kg respectively) while there no significant changes within the aerobic exercise training group (0.09, 0.07 and 0.3 kg respectively). Training-induced increased motor neuron activation and motor unit synchronization could each partly explain this finding.

Higher levels of musculoskeletal fitness (muscular strength, endurance and power) have been associated with better quality of life (Warburton, et al., 2001) and abdominal muscular endurance has been associated with a lower risk of premature mortality in Canadian adults (Katzmarzyk & Craig, 2002). The present study showed an increase in abdominal muscular endurance (partial curl-ups) in the aerobic and the combined training groups. Reductions in abdominal fat observed in all 3 exercising groups may account for the increased number of partial curl-ups (increased abdominal muscular endurance) achieved at post-intervention. We have previously reported in another paper (main HEARTY results manuscript 5) that the decreases in waist circumference were indeed higher in Aerobic (-3.7 cm) and Resistance (-4.5 cm) compared to controls and in Combined (-6.9 cm) compared to Aerobic in our most adherent sample.

Combined training was superior to aerobic training alone for increased muscular strength (leg press, bench press, seated row) and upper body muscular endurance (push-ups). However, combined training showed less leg strength improvement (leg press) compared to resistance training alone in our most adherent participants. Since the resistance exercise component was exactly the same in the resistance alone and the combined training groups and adherence rates were similar, these results suggest that the addition of aerobic exercise to resistance exercise training did not add additional benefit to improving leg muscular strength than resistance exercise training alone, and might even have had a negative effect on leg strength development. Nonetheless, Combined training increased both VO_{2peak} and musculoskeletal fitness (leg press, bench press, seated row, partial curl-ups and push-ups).

We found no within-group or between-groups differences in flexibility (sit and reach test), even when we analyzed our most adherent participants. While we did incorporate some stretching exercises in the warm-up and cool-down periods, the exercise training program evaluated in the present study was not particularly designed to increase flexibility, so this lack of change is not surprising.

The present study has some limitations. Since obesity in youth is associated with an altered motor coordination, decreased mechanical efficiency (Nantel, Brochu, & Prince, 2006; Norman, et al., 2005) and decreased exercise tolerance (Goran, Fields, Hunter, Herd, & Weinsier, 2000; Norman, et al., 2005), it is plausible that our sample of obese adolescents may have experienced greater difficulty performing some of the musculoskeletal fitness tests than slimmer adolescents would. Although the CPAFLA musculoskeletal fitness tests were performed on a large representative Canadian sample of mostly normal-weight children and adolescents (Tremblay, 2010), this is the first study to use this comprehensive musculoskeletal fitness battery of tests in a Canadian sample of overweight and obese adolescents.

Our results showed that aerobic training alone increased cardiorespiratory fitness and abdominal muscular endurance while resistance training alone increased upper and lower body muscular strength and upper body endurance in overweight and obese adolescents. Improvements in cardiorespiratory fitness after combined aerobic and resistance training were similar to those derived from aerobic training alone. Improvements in musculoskeletal fitness through combined aerobic and resistance training were similar to those from resistance exercise training alone, although resistance training alone showed greater leg strength improvements than combined training. Moreover, combined training increased both cardiorespiratory and musculoskeletal fitness compared to non-exercising controls.

Conclusion

Our findings indicate that overweight and obese adolescents participating in any form of exercise training (aerobic training alone, resistance training alone or combined aerobic and resistance training) can expect some fitness benefits while the greatest improvements in overall strength and fitness can be expected from combined aerobic and resistance exercise training. Thus, our findings provide support for prescribing the combination of aerobic and resistance exercise to maximize overall fitness, a critical component of health for overweight and obese adolescents who would otherwise be at high risk for premature morbidity and mortality.

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TABLE 1. Baseline participant characteristics.

	Aerobic	**Resistance**	**Combined**	**Control**
N	75	78	75	76
Age (years)	15.5 (1.4)	15.9 (1.5)	15.5 (1.3)	15.6 (1.3)
Weight (kg)	96.7 (15.1)	9.9 (17.4)	97.5 (16.3)	97.9 (18.8)
Height (cm)	166.9 (7.0)	168.3 (7.5)	167.5 (7.6)	168.3 (7.7)
BMI (kg/m^2)	34.7 (4.2)	35.1 (4.6)	34.6 (4.2)	34.1 (4.9)
Waist circumference (cm)	96.4 (10.1)	98.8 (11.4)	96.8 (10.5)	95.2 (11.8)
Body fat (%)	49.1 (5.8)	49.9 (5.8)	50.3 (5.3)	48.6 (5.3)
VO_{2peak} (mLO_2/kg/min)	30.6 (5.1)	29.9 (5.0)	30.5 (5.1)	30.6 (4.8)
Median adherence (%)	62	56	64	-

Values are means (SD). Abbreviations: VO_{2peak}= Peak oxygen consumption
Adherence was calculated as the number of exercise sessions attended divided by 4, since exercises were supposed to be performed 4 times per week.

TABLE 2. Baseline cardiorespiratory fitness and changes after 6 months.

Variable	N	Baseline	6 months	Absolute change from baseline to 6 months	Adjusted change from baseline to 6 months
		Mean (SE)		Mean (95% Confidence Interval)	
INTENTION-TO-TREAT ANALYSIS					
VO_{2peak} (mLO_2/kg/min)					
Aerobic	75	30.6 (0.6)	33.4 (0.7)	2.7 (1.6, 3.9)***	
Resistance	78	30.0 (0.5)	30.9 (0.7)	0.9 (-0.2, 2.0)	
Combined	75	30.6 (0.6)	32.2 (0.6)	1.6 (0.5, 2.7)***	
Control	76	30.6 (0.5)	30.9 (0.7)	0.2 (-0.8, 1.3)	
Aerobic vs. control					2.5 (0.9, 4.1)**
Resistance vs. control					0.7 (-0.9, 2.3)
Combined vs. aerobic					-1.1 (-2.7, 0.4)
Combined vs. resistance					0.7 (-0.9, 2.2)
Treadmill time (minutes)					
Aerobic	75	10.0 (0.2)	11.0 (0.2)	1.1 (0.6, 1.6)***	
Resistance	78	10.0 (0.2)	10.8 (0.2)	0.8 (0.3, 1.2)**	
Combined	75	10.2 (0.2)	11.2 (0.2)	1.0 (0.5, 1.4)***	
Control	76	10.0 (0.2)	10.2 (0.2)	0.2 (-0.3, 0.6)	
Aerobic vs. control					0.9 (0.3, 1.6)**
Resistance vs. control					0.6 (-0.1, 1.3)
Combined vs. aerobic					-0.1 (-0.8, 0.5)
Combined vs. resistance					0.2 (-0.5, 0.9)

PER-PROTOCOL ANALYSIS					
VO_{2peak} (mLO_2/kg/min)					
Aerobic	35	31.6 (0.8)	34.2 (0.9)	2.6 (1.3, 3.9)***	
Resistance	23	30.6 (0.9)	31.6 (1.0)	1.0 (-0.7, 2.6)	
Combined	29	30.5 (0.8)	32.6 (0.9)	2.2 (0.7, 3.6)**	
Control	76	30.8 (0.5)	31.0 (0.6)	0.2 (-0.8, 1.3)	
Aerobic vs. control					2.4 (0.7, 4.1)**
Resistance vs. control					0.7 (-1.2, 2.7)
Combined vs. aerobic					-0.4 (-2.4, 1.5)
Combined vs. resistance					1.2 (-1.0, 3.4)
Treadmill time (minutes)					
Aerobic	35	10.2 (0.3)	11.3 (0.3)	1.1 (0.6, 1.7)***	
Resistance	23	9.9 (0.4)	10.8 (0.4)	0.9 (0.1, 1.6)*	
Combined	29	10.2 (0.3)	11.5 (0.3)	1.3 (0.7, 1.9)***	
Control	76	10.0 (0.2)	10.2 (0.2)	0.2 (-0.3, 0.6)	
Aerobic vs. control					1.0 (0.2, 1.7)*
Resistance vs. control					0.7 (-0.2, 1.6)
Combined vs. aerobic					0.2 (-0.7, 1.0)
Combined vs. resistance					0.4 (-0.5, 1.4)

*$p<0.05$, **$p<0.01$, ***$p<0.001$.
Abbreviations: VO_{2peak}: peak oxygen consumption.

TABLE 3. Baseline musculoskeletal fitness and changes after 3 and 6 months.

		Mean (SE)			Mean (95% Confidence Interval)	
Variable	**N**	**Baseline**	**3 months**	**6 months**	**Absolute change from baseline to 6 months**	**Adjusted change from baseline to 6 months**
INTENTION-TO-TREAT ANALYSIS						
Leg press (kg)						
Aerobic	64	94 (4)	127 (7)	136 (8)	42 (28, 55)***	
Resistance	66	100 (4)	157.6 (7)	173 (8)	73 (60, 86)***	
Combined	63	110 (4)	161 (7)	174 (8)	64 (51, 78)***	
Control	60	104 (4)	126 (7)	127 (8)	23 (9, 36)***	
Aerobic vs. control						19 (2, 38)*
Resistance vs. control						50 (32, 69)***
Combined vs. aerobic						23 (4, 41)*
Combined vs. resistance						-8 (-27, 10)
Bench press (kg)						
Aerobic	63	27 (1)	30 (1)	31 (2)	4 (1, 7)**	
Resistance	65	29 (1)	38 (1)	40 (2)	12 (9, 14)***	
Combined	64	29 (1)	39 (1)	41 (2)	12 (10, 15)***	
Control	61	29 (1)	31(2)	32 (2)	3 (1, 6)*	
Aerobic vs. control						1 (-3, 5)
Resistance vs. control						8 (5, 12)***
Combined vs. aerobic						8 (5, 12)***
Combined vs. resistance						1 (-3, 5)

Seated row (kg)						
Aerobic	63	39 (1)	44 (1)	45 (2)	5 (1, 10)*	
Resistance	65	42 (1)	49 (1)	51 (2)	10 (6, 14)***	
Combined	63	41 (1)	49 (1)	55 (2)	14 (10, 18)***	
Control	61	41 (1)	46 (1)	48 (2)	7 (3, 11)**	
Aerobic vs. control						-1 (-7, 4)
Resistance vs. control						3 (-3, 9)
Combined vs. aerobic						9 (3, 15)**
Combined vs. resistance						4 (-1, 10)
Grip strength (kg)						
Aerobic	74	66 (1)	70 (2)	69 (2)	3 (1, 5)**	
Resistance	77	68 (1)	71 (2)	73 (2)	5 (3, 7)***	
Combined	75	69 (1)	72 (2)	73 (2)	4 (1, 6)***	
Control	73	68 (1)	71 (2)	71 (2)	3 (1, 5)**	
Aerobic vs. control						0 (-3, 3)
Resistance vs. control						2 (-1, 5)
Combined vs. aerobic						1 (-2, 4)
Combined vs. resistance						-1 (-5,2)

Push-ups (#)						
Aerobic	74	10 (1)	13 (1)	13 (1)	3 (1, 5)**	
Resistance	77	9 (1)	15 (1)	16 (1)	7 (5, 9)***	
Combined	75	10 (1)	16 (1)	17 (1)	7 (5, 9)***	
Control	73	9 (1)	13 (1)	12 (1)	3 (1, 5)**	
Aerobic vs. control						0 (-3, 3)
Resistance vs. control						4 (1, 6)**
Combined vs. aerobic						4 (1, 7)**
Combined vs. resistance						0 (-3, 3)
Sit and reach (cm)						
Aerobic	74	25.5 (1.1)	27.0 (1.1)	26.2 (1.2)	0.7 (-1.0, 2.3)	
Resistance	77	23.6 (1.1)	26.2 (1.1)	25.5 (1.2)	1.9 (0.3, 3.6)*	
Combined	75	25.9 (1.1)	27.7 (1.1)	26.7 (1.2)	0.8 (-0.8, 2.4)	
Control	73	23.8 (1.1)	25.5 (1.1)	24.0 (1.2)	0.1 (-1.5, 1.7)	
Aerobic vs. control						0.6 (-1.7, 2.9)
Resistance vs. control						1.8 (-0.5, 4.1)
Combined vs. aerobic						0.1 (-2.2, 2.4)
Combined vs. resistance						-1.1 (-3.5, 1.2)

Partial curl-ups (#)						
Aerobic	74	19 (1)	22 (1)	23 (1)	4 (2, 7)***	
Resistance	77	19 (1)	21 (1)	21 (1)	2 (0, 4)*	
Combined	74	18 (1)	21 (1)	22 (1)	4 (2, 7)***	
Control	72	19 (1)	21 (1)	20 (1)	1 (-1, 3)	
Aerobic vs. control						4 (1, 7)*
Resistance vs. control						2 (-1, 5)
Combined vs. aerobic						0 (-3, 3)
Combined vs. resistance						2 (-1, 5)
Leg power (watts)						
Aerobic	74	4032 (93)	4009 (97)	4095 (98)	62 (-69, 193)	
Resistance	77	4222 (92)	4183 (95)	4283 (97)	61 (-69, 192)	
Combined	74	4102 (93)	4134 (96)	4107 (96)	5 (-123, 134)	
Control	73	4158 (93)	4154 (99)	4199 (95)	41 (-85, 166)	
Aerobic vs. control						22 (-160, 203)
Resistance vs. control						21 (-161, 202)
Combined vs. aerobic						-57 (-240, 127)
Combined vs. resistance						-56 (-239, 127)

PER-PROTOCOL ANALYSIS						
Leg press (kg)						
Aerobic	29	89 (6)	129 (9)	135 (11)	46 (29, 63)***	
Resistance	18	112 (8)	185 (11)	214 (13)	101 (80, 123)***	
Combined	24	104 (7)	154 (10)	169 (12)	65 (46, 85)***	
Control	60	105 (4)	127 (7)	127 (8)	22 (9, 36)**	
Aerobic vs. control						24 (2, 45)*
Resistance vs. control						79 (54, 104)*
Combined vs. aerobic						19 (-6, 45)
Combined vs. resistance						-36 (-65, -7)*
Bench press (kg)						
Aerobic	28	27 (2)	31 (2)	32 (2)	5 (1, 8)**	
Resistance	18	31 (2)	43 (3)	48 (3)	17 (12, 21)***	
Combined	25	27 (2)	40 (2)	43 (3)	16 (12, 19)***	
Control	61	29 (1)	31 (2)	33 (2)	3 (1, 6.)*	
Aerobic vs. control						2 (-3, 6)
Resistance vs. control						13 (8, 18)***
Combined vs. aerobic						11 (5, 16)***
Combined vs. resistance						-1 (-7, 5)

Seated row (kg)						
Aerobic	28	41 (2)	45 (2)	46 (3)	6 (0, 12)	
Resistance	17	45 (3)	55 (3)	59 (4)	14 (7, 22)***	
Combined	25	38 (2)	48 (2)	59 (3)	21 (14, 27)***	
Control	61	41 (1)	46 (1)	48 (2)	7 (2, 12)**	
Aerobic vs. control						-1 (-9, 6)
Resistance vs. control						8 (-1, 16)
Combined vs. aerobic						15 (6, 24)**
Combined vs. resistance						6 (-4, 16)
Grip strength (kg)						
Aerobic	35	67 (2)	72 (2)	71 (2)	4 (1, 6)**	
Resistance	23	71 (3)	74 (3)	77 (3)	6 (3, 9)***	
Combined	29	70 (2)	70 (2)	74 (3)	4 (1, 7)*	
Control	73	69 (1)	72 (2)	72 (2)	3 (1, 5)**	
Aerobic vs. control						1 (-3, 4)
Resistance vs. control						3 (-1, 7)
Combined vs. aerobic						0 (-4, 5)
Combined vs. resistance						-2 (-7, 3)

Push-ups (#)						
Aerobic	35	11 (1)	15 (2)	15 (2)	4 (1,6)**	
Resistance	23	9 (2)	16 (2)	17 (2)	8 (5, 11)***	
Combined	29	11 (2)	18 (2)	19 (2)	8 (6, 11)***	
Control	73	9 (1)	13 (1)	12 (1)	3 (1, 5)***	
Aerobic vs. control						1 (-2, 3)
Resistance vs. control						5 (2, 8)**
Combined vs. aerobic						5 (2, 8)**
Combined vs. resistance						0 (-3, 4)
Sit and reach (cm)						
Aerobic	35	27.2 (1.6)	27.6 (1.6)	27.4 (1.7)	0.2 (-1.9, 2.3)	
Resistance	23	25.2 (2)	28.1 (2)	26.7 (2.1)	1.5 (-1.1, 4.1)	
Combined	29	27.0 (1.8)	27.5 (1.8)	26.9 (1.9)	-0.1(-2.5, 2.3)	
Control	73	23.6 (1.1)	25.2 (1.2)	23.7 (1.2)	0.1 (-1.5, 1.7)	
Aerobic vs. control						0.1 (-2.5, 2.7)
Resistance vs. control						1.4 (-1.6, 4.5)
Combined vs. aerobic						-0.3 (-3.4, 2.9)
Combined vs. resistance						-1.6 (-5.1, 1.9)

Partial curl-ups (#)						
Aerobic	35	20 (1)	24 (1)	24 (1)	4 (2, 7)**	
Resistance	23	20 (2)	23 (1)	23 (1)	3 (0, 7)*	
Combined	29	21 (2)	23 (1)	24 (1)	2 (-1, 5)	
Control	72	19 (1)	21 (1)	20 (1)	1 (-1, 3)	
Aerobic vs. control						4 (0, 7)*
Resistance vs. control						3 (-1, 6)
Combined vs. aerobic						-2 (-6, 2)
Combined vs. resistance						-1 (-5, 4)
Leg power (watts)						
Aerobic	35	4042 (141)	3968 (139)	4077 (135)	34 (-131, 199)	
Resistance	23	4391 (173)	4410 (171)	4578 (167)	187 (-18, 392)	
Combined	28	4067 (156)	4027 (153)	4017 (152)	-50 (-242, 143)	
Control	73	4189 (97)	4191 (100)	4232 (97)	43 (-84, 169)	
Aerobic vs. control						-8 (-216, 200)
Resistance vs. control						145 (-97, 386)
Combined vs. aerobic						-84 (-337, 170)
Combined vs. resistance						-237 (-518, 44)

*p<0.05, **p<0.01, ***p<0.001.
Note: Leg power in watts was calculated from the vertical jump test using the formula by Sayers et al. (Sayers, et al., 1999).

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CHAPTER V: FINAL DISCUSSION

Final discussion

The adolescent period is characterized by a multitude of physiological and behavioral changes compounded by external factors in our obesogenic environment that play roles in the onset, development and persistence of obesity (5). Drastic declines in physical activity, sport participation, cardiorespiratory and musculoskeletal fitness during the adolescent years (7-8) are a public health concern and warrant interventions to promote and maintain physically active lifestyles during this critical period and throughout the lifespan. Since a substantial proportion of adolescents with obesity already show signs of impaired cardiometabolic health (16-17) and regular exercise training is associated with reductions in CVD risk and premature mortality (25), it becomes imperative to identify effective exercise training interventions to improve the cardiometabolic health of overweight and obese adolescents.

The three published systematic reviews (5, 26, 30) and the methodology paper (32) (manuscripts 1-4) of this dissertation clearly demonstrate the paucity of well-controlled exercise interventions in overweight and obese adolescents. These systematic reviews were conducted to identify the knowledge gaps in the literature regarding the effects of exercise training in the management of adolescent obesity and its co-morbidities and to provide additional support for the already ongoing HEARTY trial. The results of these systematic reviews highlighted the need for an adequately powered, longer exercise intervention (>16 weeks) examining the effects of aerobic training, resistance training and combined training using gold-standard body composition, CVD risk markers, RMR, and fitness assessment techniques in a large sample of post-pubertal obese adolescents.

Although the main outcome of the HEARTY trial (manuscript 5) was percent body fat measured by MRI, the specific objectives proposed for my dissertation were to investigate in further detail the effects of aerobic training, resistance training and their combination on abdominal fat, traditional and non-traditional CVD risk markers, RMR, and cardiorespiratory and musculoskeletal fitness in obese adolescents who participated in the HEARTY trial. We observed no significant changes in fasting glucose, post-load glucose, hemoglobin A1c (HbA1c), high density lipoprotein cholesterol (HDL), low density lipoprotein cholesterol (LDL), triglycerides and high-sensitivity C-reactive protein (HSCRP) in any exercise group in either the intention-to-treat or the per-protocol analyses. However, the HEARTY trial results showed significant decreases in percent body fat and waist circumference in all three exercise training groups and the largest declines in percent body fat and waist circumference were observed in the combined training group, especially in the most adherent participants. These findings suggest that obese adolescents who participate in any type of exercise training (aerobic, resistance or both) could expect some cardiometabolic health benefits regardless of the exercise modality they choose but the greatest health benefits are associated with a greater volume of exercise training. In participants adhering to the exercise protocol (≥ 2.8 sessions per week), combined training was more effective than either type of exercise alone in decreasing percent body fat, waist circumference and BMI in a large sample of obese adolescents exercising in community-based exercise facilities.

Increased abdominal fat is associated with greater cardiometabolic risk (12, 33-34) and non-traditional CVD risk factors such as HSCRP, Apolipoproteins A-1 and B (ApoA-1 and ApoB) and the ratio ApoB/ApoA-1 have emerged as important independent biomarkers for CVD risk (35-36). Results presented in manuscript 6 showed significant reductions in abdominal subcutaneous fat (SAT) within all exercise groups. While resistance training alone decreased superficial subcutaneous fat, aerobic training alone decreased the deeper layer of SAT.

Combined training decreased ApoB and ApoB/ ApoA-1 ratio compared to control and only the differences in ApoB/ApoA-1 ratio were greater in the combined training group compared to aerobic training alone. This is of paramount importance given that ApoB and ApoB/ApoA-1 ratio have recently been identified as important independent non-traditional risk factors associated with a greater risk of CVD (36).

Given that obesity is the result of an energy imbalance and that RMR accounts for the greatest percentage of total energy expenditure per day (31), manuscript 7 examined whether or not the exercise modalities used in the HEARTY trial could increase the number of calories burned at rest and thus promote a negative energy balance to assist with weight loss in overweight and obese adolescents. However, our results showed that 6 months of aerobic training, resistance training and combined training did not reduce body weight and did not increase RMR. Only our most adherent participants in the combined group compared to controls decreased their body weight. If weight loss is the goal for obese adolescents beginning an exercise program, they should be conscious not to increase their energy intake above baseline levels, as resting energy expenditure will probably not increase through exercise training. It is important to note, however, that energy expenditure from participation in structured and non-structured physical activity also play roles in total energy expenditure (in addition to resting metabolic rate) and can assist with energy balance. There were no changes in background physical activity as reflected in step counts (excluding study exercise sessions) during the intervention, although adherence to pedometer use was poor. While even normal-weight adolescents would gain some weight during a 6-month interval (37) due to anabolism and growth in lean tissue, participants in the HEARTY trial did not gain body weight, suggesting that involvement in the trial might have prevented weight gain that may otherwise have occurred.

The exercise interventions used in the HEARTY trial did show, however, that combined training improved cardiorespiratory and musculoskeletal fitness (manuscript 8) which can have important health benefits for the prevention of CVD and premature mortality.

Taken together, the overall results of this dissertation suggest that combined aerobic and resistance exercise training showed the greatest improvements in cardiometabolic health (body composition, abdominal fat, ApoB, ApoB/ApoA-1 ratio, cardiorespiratory and musculoskeletal fitness) in overweight and obese adolescents who participated in the HEARTY trial.

Table 1 below summarizes the findings of this dissertation. Differences were only considered significant if changes in the exercise group (Aerobic, Resistance or Combined) were significantly different from Control. Results from intention-to-treat (includes the whole sample regardless of their adherence rate and includes those who later withdrew) and per-protocol analyses were amalgamated into this summary table to better understand the effects of aerobic and resistance exercise training in obese adolescents.

The additional comparison of Combined vs. Control was not a pre-specified comparison so it was not included in the results of manuscripts 5-8 but was included in the following summary table for comparison. Notably, in intention-to-treat analyses, decreases in Combined vs. Control were significant for BMI, waist circumference, waist-to-hip ratio, total cholesterol, ApoB and ApoB/ApoA-1 ratio. With per-protocol analyses, decreases in body weight, BMI, waist circumference and waist-to-hip ratio were significantly different when comparing Combined vs. Control.

Table 1. Summary of the effects of aerobic training, resistance training and combined exercise training on cardiometabolic health measures in obese adolescents by intention-to-treat (ITT) and per-protocol (PP) analyses.

EXERCISE TRAINING MODALITY	CARDIOMETABOLIC HEALTH MEASURES								
	BODY COMPOSITION				CVD RISK MARKERS†		RMR	FITNESS	
	Body weight	BMI	% body fat	Abdominal fat (waist, SAT, VAT)	Traditional†	Non-traditional ‡		CRF	Musculoskeletal
Aerobic training	↔ $^{\text{ITT, PP}}$	↔ $^{\text{ITT}}$ ↓ $^{\text{PP}}$	↔ $^{\text{ITT}}$ ↓ $^{\text{PP}}$	↓ waist $^{\text{ITT, PP}}$ ↔ VAT $^{\text{ITT, PP}}$ ↓ SAT $^{\text{ITT, PP}}$ ↔ supSAT $^{\text{ITT, PP}}$ ↓ deepSAT $^{\text{ITT, PP}}$	↔ $^{\text{ITT, PP}}$	↔ $^{\text{ITT, PP}}$	↔ $^{\text{ITT, PP}}$	↑ $^{\text{ITT, PP}}$	↑ Lower body strength $^{\text{ITT, PP}}$ ↔ Upper body strength & endurance $^{\text{ITT, PP}}$ ↑Abdominal endurance $^{\text{ITT, PP}}$ ↔ Flexibility $^{\text{ITT, PP}}$ ↔ Leg power $^{\text{ITT, PP}}$
Resistance training	↔ $^{\text{ITT, PP}}$	↔ $^{\text{ITT, PP}}$	↓ $^{\text{ITT, PP}}$	↓ waist $^{\text{ITT, PP}}$ ↔ VAT $^{\text{ITT, PP}}$ ↓ SAT $^{\text{ITT}}$ ↓ supSAT $^{\text{ITT}}$ ↔ deepSAT $^{\text{ITT, PP}}$	↔ $^{\text{ITT}}$	↔ $^{\text{ITT, PP}}$ ↓fasting insulin $^{\text{PP}}$	↔ $^{\text{ITT, PP}}$	↔ $^{\text{ITT, PP}}$	↑ Lower body strength $^{\text{ITT, PP}}$ ↑ Upper body strength & endurance $^{\text{ITT, PP}}$ ↔ Abdominal endurance $^{\text{ITT, PP}}$ ↔ Flexibility $^{\text{ITT, PP}}$ ↔ Leg power $^{\text{ITT, PP}}$
Combined training	↔ $^{\text{ITT}}$ ↓ $^{\text{PP}}$	↓ $^{\text{ITT, PP}}$	↓ $^{\text{ITT, PP}}$	↓ waist $^{\text{ITT, PP}}$ ↔ VAT $^{\text{ITT, PP}}$ ↓ SAT $^{\text{ITT, PP}}$ ↓ supSAT $^{\text{ITT, PP}}$ ↓ deepSAT $^{\text{PP}}$	↓total cholesterol $^{\text{ITT}}$ ↔ $^{\text{PP}}$	↓ApoB $^{\text{ITT}}$ ↓ApoB/Apo A-1 $^{\text{ITT}}$ ↔ $^{\text{PP}}$	↔ $^{\text{ITT, PP}}$	↔ $^{\text{ITT}}$ ↑ $^{\text{PP}}$	↑ Lower body strength $^{\text{ITT, PP}}$ ↑Upper body strength & endurance $^{\text{ITT, PP}}$ ↑Abdominal endurance $^{\text{ITT}}$ ↔ Flexibility $^{\text{ITT, PP}}$ ↔ Leg power $^{\text{ITT, PP}}$

Symbols: ↔ no significant change, ↑ significant increase and ↓ significant decrease (when exercise group was compared to control group). For the purposes of this dissertation, † traditional CVD risk factors include high density lipoprotein cholesterol (HDL), low density lipoprotein cholesterol (LDL), triglycerides, systolic and diastolic blood pressure, fasting glucose, post-load glucose (after an oral glucose tolerance test) and HbA1c. ‡ Non-traditional CVD risk factors include fasting insulin, high-sensitivity C-reactive protein, ApoA-1, ApoB and ApoB/ApoA-1 ratio. **Abbreviations:** ApoA-1= apolipoprotein A-1, ApoB= apolipoprotein B, BMI= body mass index, CRP= cardiorespiratory fitness, CVD= cardiovascular disease, deepSAT= deep layer of subcutaneous fat, ITT= intention-to-treat analysis (includes the entire sample, regardless of adherence and includes those who later withdrew), PP= per-protocol analysis (includes the sample with ≥70% adherence), RMR= resting metabolic rate, SAT= subcutaneous fat, supSAT= superficial layer of subcutaneous fat, VAT= visceral fat, waist= waist circumference. **Note:** Combined training was superior to Aerobic training for changes in percent body fat, BMI, waist, ApoB/ApoA-1 ratio, lower & upper body strength and upper body endurance. Combined training was superior to Resistance training for changes in BMI.

These results emphasize that a higher exercise training volume including a combination of aerobic and resistance exercise incorporating whole-body exercises at a moderate to high intensity, performed at least 3 times per week yields significant health benefits to obese adolescents. Although the exercise training interventions did not change RMR or the CVD risk markers, there were significant reductions in percent body fat, BMI, waist circumference, abdominal fat, and increases in cardiorespiratory and musculoskeletal fitness in the combined aerobic and resistance exercise training group.

Despite the positive results showing improvements in the cardiometabolic health of our HEARTY participants, the median exercise adherence range (56-64%) was lower than anticipated. Moreover, the analysis of the data of our most adherent participants in the combined group (≥70% adherence= 2.8 sessions/ week) yielded the greatest improvements (body weight, percent body fat, BMI, waist circumference, abdominal fat, cardiorespiratory and musculoskeletal fitness) providing added support to the notion that greater volume of exercise training produces greater health benefits.

The results of the HEARTY trial and the compilation of research in this dissertation suggest that future research should move beyond the oversimplification of the ‘eat-less-exercise-more’ paradigm in the management of adolescent obesity. The obesogenic environment that we live in compounded by the multifactorial etiology of obesity and the multitude of physiological and psychosocial changes that occur during adolescence make obesity management especially challenging and difficult in youth. Perhaps it is time for public health agencies to switch their focus of promoting exercise for weight loss to promoting exercise for improvements in overall health in youth.

Future research directions and practical applications

The lack of improvement in CVD risk markers (HDL, LDL, triglycerides, blood pressure, fasting glucose, post-load glucose, HbA1c, HSCRP) following training warrants further investigation. A possible explanation for the lack of change is possibly because as a group, our participants had relatively normal values at baseline (86% of our study participants had normal glucose tolerance). Future studies should examine the effects of exercise training in both metabolically healthy versus metabolically unhealthy obese adolescents to determine if there are differences in their responses to exercise.

Canadian youth spend ~8.6 hrs/day in sedentary behavior such as sitting or lying down playing inactive video games or being in front of the television or computer (38). Higher levels of sedentary behavior have been associated with greater cardiometabolic risk and premature mortality independent of physical activity levels (39-41). Although the HEARTY trial aimed to increase structured physical activity through our exercise program, future secondary analyses should investigate whether participation in HEARTY also had an impact on participation in non-structured physical activity pursuits and time spent in sedentary behaviors after completion of the trial.

Although this dissertation focused on the effects of exercise training on physiological health, it is clear from manuscript 1 that important psychosocial changes occur during the critical period of adolescence that likely affect the onset, development and progression of obesity throughout the lifespan. The effects of different exercise modalities on psychosocial health also warrant further study and current analyses are underway to determine the effect of the HEARTY trial on multiple psychosocial outcomes.

Our results showcase that our most adherent participants demonstrated greater health benefits following the exercise intervention. Only 54% of our participants adhered to ≥2.8 sessions/ week (per-protocol analysis n=161 compared to intention-to-treat analysis n=297). This highlights the need to determine how the adherent participants differ from the drop-outs of our study. A recent cluster analysis examined this question in the largest study of individuals successful at maintaining weight loss (the National Weight Control Registry) and showed that there are different clusters of participant characteristics, strategies and attitudes that help individuals achieve successful weight goals (42). Future secondary analyses should examine which demographic, physiological and psychological factors in our HEARTY participants were associated with greater adherence and marked improvements in cardiometabolic health following the 6-month intervention. Acquiring such information could better design future exercise programs and assist adolescents who are seeking to improve their overall health.

Future studies should be conducted to evaluate how the long term exercise adherence to interventions such as the one used in the HEARTY trial could be improved. This is very relevant considering that only 7% of Canadian children and youth aged 6-19 years old partake in at least 60 minutes of moderate to vigorous physical activity every day (38). Furthermore, the median exercise adherence in our trial was 62% in aerobic, 56% in resistance and 64% in combined, with no significant differences between groups. These lower-than-anticipated adherence rates from the HEARTY trial inspired the purpose of the final manuscript 9 included in this dissertation. Based on our HEARTY clinical trial experience and the literature review, we identified practical lessons that could potentially decrease participant attrition, promote exercise adherence and maximize the health benefits from regular exercise in overweight and obese youth. The ten lessons are: 1. Physical activity setting-context is important; 2. Choice of fitness trainer matters;

3. Physical activities should be varied and fun; 4. The role of the parent-guardian should be considered; 5. Individual physical and psychosocial characteristics should be accounted for; 6. Realistic goals should be set; 7. Regular reminders should be offered; 8. A multidisciplinary approach should be taken; 9. Barriers should be identified early and a plan to overcome them developed; and 10. The right message should be communicated: specifically, what's in it for them?.

Applying these ten recommendations could improve the design of future exercise programs for youth. We believe that these practical lessons will serve as a guide to families, physical education teachers, personal trainers, exercise specialists, exercise facility managers, clinicians, investigators and policy makers to optimize the multidimensional health benefits associated with participation in structured physical activity programs in youth. However, future research is needed to evaluate the proposed ten practical recommendations and determine their effectiveness in increasing adherence to exercise programs and improving overall health of children and adolescents with obesity.

MANUSCRIPT 9: Top 10 practical lessons learned from physical activity interventions in overweight and obese children and adolescents

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Permission was granted to include the published version of this article in this dissertation (Appendix).

Statement of contributions of collaborators:

A.S. Alberga conceived the topic and content of this knowledge translation/ practical application manuscript, carried out a bibliographic search, article screening and drafted and edited the manuscript. E. Medd assisted with the bibliographic search, article screening, and assisted in the drafting and editing of the manuscript. Drs. Adamo, Goldfield, Prud'homme, Kenny and Sigal provided analytical input, and helped draft and edit the manuscript.

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ARTICLE

Top 10 practical lessons learned from physical activity interventions in overweight and obese children and adolescents

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Abstract: Physical activity (PA) interventions targeting overweight and obese children and adolescents have shown only modest success, and dropout is an area of concern. Proper design and implementation of a PA intervention is critical for maximizing adherence and thus increasing the overall health benefits from PA participation. We propose practical advice based on our collective clinical trial experience with support from the literature on best practices related to PA interventions in overweight and obese children and adolescents. The top 10 lessons learned are (*i*) PA setting–context is important; (*ii*) choice of fitness trainer matters; (*iii*) physical activities should be varied and fun; (*iv*) the role of the parent–guardian should be considered; (*v*) individual physical and psychosocial characteristics should be accounted for; (*vi*) realistic goals should be set; (*vii*) regular reminders should be offered; (*viii*) a multidisciplinary approach should be taken; (*ix*) barriers should be identified early and a plan to overcome them developed; and (*x*) the right message should be communicated: specifically, what's in it for them? The recommendations in this paper can be used in other pediatric PA programs, physical education settings, and public health programs, with the hope of decreasing attrition and increasing the benefits of PA participation to promote health in children and adolescents.

Key words: physical activity, obesity, overweight, child, adolescent, intervention, resistance training, aerobic training, adherence, compliance.

Résumé : Les interventions par l'activité physique s'adressant aux enfants obèses et à ceux présentant un surpoids ont connu un succès mitigé et l'abandon de la pratique est un sujet préoccupant. La conception judicieuse et la mise en œuvre des interventions au moyen de l'activité physique sont d'une importance capitale pour maximiser le maintien de la pratique et améliorer de ce fait la santé globale de cette population. Nous donnons les conseils pratiques suivants à la lumière de notre expérience clinique de groupe et de la documentation au sujet des meilleures pratiques d'interventions par l'activité physique auprès d'enfants et d'adolescents obèses et présentant un surpoids. Les 10 conseils les plus importants sont : (*i*) le contexte–milieu de pratique de l'activité physique est important, (*ii*) le choix de l'entraîneur physique compte, (*iii*) les activités physiques sélectionnées doivent être diversifiées et amusantes, (*iv*) on doit envisager un rôle pour le parent–tuteur, (*v*) on doit prendre en compte les caractéristiques physiques et psychosociales individuelles, (*vi*) on doit fixer des objectifs réalistes, (*vii*) on doit faire régulièrement des rappels, (*viii*) on doit utiliser une approche multidisciplinaire, (*ix*) on doit identifier rapidement les obstacles et élaborer un plan pour les éliminer et (*x*) on doit communiquer le vrai message : dire spécifiquement pourquoi on le fait. Les recommandations dans cet article peuvent être utilisées pour d'autres programmes d'activité physique à l'intention des enfants et des adolescents, dans d'autres milieux d'éducation physique et de santé publique, et ce, dans l'espoir de diminuer l'abandon de la pratique de l'activité physique et d'en tirer des bénéfices sur le plan sanitaire pour cette population. [Traduit par la Rédaction]

Mots-clés : activité physique, obésité, surpoids, enfant, adolescent, intervention, entraînement contre résistance, entraînement aérobie, adhésion, compliance.

Introduction

Physical activity (PA) and the physical fitness levels of children and adolescents have declined in the past few decades (Tomkinson and Olds 2007; Tremblay et al. 2010). Exercise interventions targeting overweight children and adolescents have been only modestly successful, and dropout is of great concern. Despite the well-known benefits of exercise, PA interventions tend to have highly variable adherence rates (Pavey et al. 2012), diminishing the potential health benefits for participants. The focus of exercise interventions in overweight youth should not be on weight loss alone, given that exercise has also resulted in improvements in body composition (Gutin et al. 2002), fitness (Gutin et al. 2002), blood profile, (Shaibi et al. 2006), and well-being (Yu et al. 2008). Proper design and implementation of strategies to maintain or increase PA adherence are critical to maximizing the overall health benefits associated with a physically active lifestyle. Although some predictors of dropout from PA interventions have been identified in obese youth (de Niet et al. 2011; Jelalian et al. 2008), practical advice on how to improve the design of these interventions and to encourage adherence is lacking.

This manuscript reviews 10 of the most pertinent lessons we have learned as physicians, psychologists, scientists, research staff, educators, exercise specialists, and personal trainers involved in PA research intervention trials targeting overweight and obese children and adolescents. We compiled retrospectively a list of the most recurrent issues we encountered while working with children and adolescents in various PA settings. Because of significant overlap among these issues, we selected recommendations that encompassed all our practical advice and compiled them into

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a concise list of 10 lessons. Once these 10 practical lessons were selected (they do not appear in order of importance), we sought and cited published intervention studies that targeted children and youth to support each of our recommendations. For this manuscript, use of the word "physical activity" (PA) refers mostly to planned, structured PA and exercise interventions rather than unstructured activity (any physical movement that may increase daily minutes of PA). When we refer to "children" we mean those aged ≤12 years and when we refer to "adolescents" we mean those between the ages of 13 and 18 years.

1. PA setting–context is important

Both the physical and the sociocultural environment are predictors of PA and should be considered when designing PA interventions for overweight and obese youth (Franzini et al. 2009; Sallis et al. 2000).

1.1. Physical environment

PA intervention settings for overweight youth should be accessible. In the preschool population, more portable equipment on the playground, less fixed playground equipment, and a larger playground size were associated with more minutes of moderate to vigorous PA and less time in sedentary activity (Dowda et al. 2009). It was found that the characteristics of the preschool attended had a greater influence on the PA level of preschoolers than did sociodemographic factors (age, sex, race–ethnicity, parent education, body mass index (BMI)) (Pate et al. 2004). Frequency of exposure to play spaces, time spent there, and convenience of play spaces were found to be positively correlated with (unstructured) PA in children 4 years of age (Sallis et al. 1993). Access to facilities is positively associated with PA level in children (Sallis et al. 2000) and is negatively associated with obesity in adolescents (Dunton et al. 2009). In the Girls' health Enrichment Multi-site Study (GEMS), an afterschool weight-loss intervention in 61 African-American girls aged 8 to 10 years, transportation was reported as the main barrier to participation (Robinson et al. 2003). This indicates that to promote facility-based PA adherence, the provision of or reimbursement for transportation may need to be considered for participants. Alternatively, a possible solution for individuals with barriers to transportation is a home-based PA intervention. However, participants training at fitness facilities may experience a different social environment (see section 1.2). Evidence also suggests that music may be incorporated into the PA program to increase motivation and reduce awareness of the body and (or) physical discomfort (De Bourdeaudhuij et al. 2002). Notably, music used as a distraction increased exercise tolerance and perseverance on a treadmill test in a sample of overweight and obese youth aged 9 to 17 years (De Bourdeaudhuij et al. 2002) and increased exercise duration in overweight or obese adolescents aged 12 to 17 years (Adamo et al. 2010).

1.2. Sociocultural environment

Increased PA participation in children has been associated with a favourable social environment as indicated by higher scores on collective socialization, collective efficacy, social ties, perceived safety, and neighbourhood exchange (how often neighbours exchange favours) (Franzini et al. 2009). This relationship was observed even when controlling for sociodemographic factors such as age, sex, race–ethnicity, and parent education. To promote PA adherence, Deforche et al. (2011) recommend capitalizing on what motivates participants to exercise. Motivators for adolescent girls were found to be both extrinsic (being thin) and intrinsic (overcoming challenges, developing a sense of accomplishment) (Gillison et al. 2011). Understanding and documenting all motivators will allow the PA program developers to modify the setting to emphasize or promote intrinsic motivators, thereby increasing the participant's autonomy with regard to PA. Deforche et al. (2011) suggest that group exercise sessions may promote long-term PA behaviours. In obese boys (8–12 years), PA level and motivation to be physically active were shown to be greater in the presence of friends and peers (regardless of friends' weight status) than when PA was performed alone or with family members (Salvy et al. 2012).

Fostering positive social interactions and team-building activities are important in group PA settings. Interacting with others in an inclusive environment appears to be an important factor when promoting PA. From a sample of 122 adolescents aged 13 to 17 years (BMI unknown), those who were randomized to an exercise group that incorporated team-building activities demonstrated greater exercise adherence compared with the control group, who participated in exercise alone (Bruner and Spink 2011). Team-building activities and (or) frameworks have also been employed in PA interventions for overweight or obese children and adolescents. A weight-loss intervention called REACH for obese children (mean age, 14.6 years) that used group-mediated cognitive behaviour techniques found that minutes of PA per week, self-regulatory efficacy, and enjoyment of PA all significantly increased after the intervention (Wilson et al. 2012). It is suggested that team-building PA may be effective for overweight and obese children and adolescents in groups in which they feel equal to their peers, included, and emotionally secure. Group-based training appears to be effective for overweight and obese children and adolescents, provided the physical setting (see section 1.1) is taken into consideration. It has been shown that overweight adults were more embarrassed and intimidated about exercising in health clubs and exercising around fit and younger people than were nonoverweight adults, and overweight women were more embarrassed than were overweight men (Millar and Millar 2010). Although no such evidence about perceptions of exercise facilities has been shown in overweight and obese youth, health clubs (e.g., exercise clubs, fitness facilities, gyms, etc.) may not be the optimal setting in which to attempt to increase PA for overweight and obese adolescents if they feel uncomfortable and self-conscious in that environment.

Social interaction can also have a negative impact on PA, especially for overweight and obese children and adolescents. The PA level of normal-weight youth (aged 8–12 years) decreases with negative peer interactions such as ostracism (Salvy et al. 2012), a scenario that may be more likely in obese youth (Stankov et al. 2012). Data from 1520 boys and girls show that by 14 years of age, obese youth had lower self-esteem than did nonobese youth (Strauss 2000). This was associated with feelings of loneliness, nervousness, and sadness (Strauss 2000). As well, overweight adolescent girls have reported more stigmatizing experiences in the presence of boys than when with same-sex peers (Neumark-Sztainer et al. 1998). Obese youths' comparisons with their peers are generally negative and can result in perceptions of inferiority (Stankov et al. 2012). It is advised that the focus of interventions be on the participant's effort during PA to adhere to healthy behaviours rather than on the outcomes (Deforche et al. 2011).

The participants' social and cultural beliefs and customs should also be considered carefully. In children aged 4 years, unstructured PA at home was negatively correlated with number of indoor and outdoor play rules (Sallis et al. 1993). A systematic review of qualitative studies examining barriers to PA for adolescents determined that components of the environment and social norms may increase an adolescent's feelings of being on display and could limit his or her participation in PA (e.g., set activities in physical education class such as jumping or swimming, tight physical education uniforms, lack of privacy in change rooms, etc.) (Stankov et al. 2012). The authors suggest that physical education uniforms, as well as the range of activities offered, should accommodate all body types, and that students be allowed to change their clothing in private.

While the influence of the social environment may apply to all age groups it is thought to be particularly important for adolescents undergoing puberty because adolescence has been identified as a critical and sensitive period for physiological and psychological development (Alberga et al. 2012; Dietz 1997). A respectful and welcoming environment should be established early to ensure the participants are comfortable and feel secure in their interactions with others.

2. Choice of fitness trainer matters

Fitness trainers play a strong role in creating a positive environment for participants in a PA program or intervention. Creating such an environment can be accomplished by having all staff (and other participants if present) introduce themselves and by allowing time for familiarization with the fitness and sports equipment. Deforche et al. (2011) recommend that the trainer know the names of the participants and treat the participants as their equals by not making them feel like the trainer is their parent, teacher, or specialist but more of a friend and mentor (Pescud et al. 2010). Overweight children aged 6 to 13 years who participated in a resistance-training intervention reported enjoying the social interactions and development of friendships with other children and their trainers (Pescud et al. 2010). Friendship was identified as an important factor in continued participation during the program and was especially valued in girls (Pescud et al. 2010). Participant preference regarding the sex of their trainer should also be taken into consideration, especially for cultural and ethnic sensitivity reasons. Although this preference has not yet been established with overweight and obese children and adolescents, having a same-sex athletic trainer has been associated with a greater comfort level in collegiate athletes (Drummond et al. 2007).

The characteristics of a good trainer that we identified include a strong knowledge of youth PA and healthful growth and development, empathy, enthusiasm, patience, genuine care for the well-being of the participants, sensitivity to their insecurities, and good communication skills. Trainers should be chosen carefully because they have the potential to be role models and have a powerful influence on the child's or adolescent's attitude and future PA participation. Trainers should be selected based on their ability to communicate simply and effectively to children, as well as on their knowledge of the sciences of PA and exercise and their ability to design and teach safe and effective exercises to children and adolescents.

Along with a required background in kinesiology, fitness trainers working with obese children and adolescents should comprehend the multifactorial etiology and complexity of obesity. Trainers should have experience working with individuals with chronic disease and should have a good understanding of both the physiological and the psychosocial issues associated with obesity in childhood and adolescence, to combat the pervasiveness of weight bias and obesity stigma (Puhl and Heuer 2009). Peer training may be another potential strategy for promoting PA, when peer trainers receive adequate training from the intervention staff to help deliver the program. A randomized controlled trial based on a peer health education program found that sedentary activity decreased in a sample of grade 7 children being educated by their peers (Cui et al. 2012). This peer training paradigm was found to be feasible, effective, and valued by participants (Shah et al. 2011). Another health promotion program, called Healthy Buddies, engaged older students (grades 4–7) to be peer teachers for their younger "buddies" (students in kindergarten to grade 3) (Stock et al. 2007). This program showed a positive impact on the health (BMI), health knowledge, attitudes, and behaviours of both the younger students and the peer teachers (Stock et al. 2007). However, because neither of these trials compared peer teaching with adult teaching, it is unclear whether the results were due to the instruction by peers or to the intervention itself. Furthermore, the HEALTHY intervention (a 3-year, school-based randomized controlled trial that included nutrition, physical education, behaviour, and health communication components) had a significant effect on obesity prevalence in adolescents who made a public commitment to the trial by actively participating in health-promotion activities as peer leaders (DeBar et al. 2011). Further research is needed to determine the effectiveness of peer training and to compare it with more traditional types of adult-led exercise training interventions.

3. Physical activities should be varied and fun

A structured exercise program is typically a component of health interventions targeting overweight and obese youth; however, exercise adherence may depend on the program design. A variety of exercises should be prescribed and should reflect the participants' preferences (Deforche et al. 2011). The activities should be mastered easily (providing participants with an early sense of success) and progressive (developing general motor skills at the beginning of the program) to motivate exercise adherence (Sothern et al. 1999*a*).

Obese youth generally have poorer performance on aerobic and weight-bearing activities (e.g., jogging) compared with nonobese youth (Deforche et al. 2003). One session of aerobic exercise of long duration may be perceived as monotonous and challenging for obese children and adolescents. In these circumstances, it may be desirable to involve the fitness trainer in the exercise with the participant to decrease boredom and to motivate the participant, especially if he or she is exercising alone. Moreover, group exercise sessions and (or) peer teaching (see sections 1.2 and 2.0) may be more enjoyable for youth. Alternating the type of aerobic exercise in different sessions (i.e., elliptical machine, group exercise session, treadmill, bike, rowing, etc.) and asking the participant's exercise preference may help make PA more enjoyable. Non-weight-bearing aerobic exercises (e.g., biking, rowing, etc.) should be incorporated at the beginning of an exercise program for overweight and obese youth. More weight-bearing activities (e.g., jogging, running, etc.) could be added as physical fitness and confidence increase throughout the program.

Research has shown that supervised, progressive, and age-specific resistance training (strength training or weight training) can be employed safely and effectively (Faigenbaum et al. 2009) in a multidisciplinary weight-management intervention for obese children aged 7 to 12 years (Bernhardt et al. 2001; Sothern et al. 1999*b*) and may improve exercise program adherence for obese youth because of greater perceived competence and less discomfort compared with aerobic-type activities (Deforche et al. 2003). At the start of a resistance exercise program, incorporating exercises in which most of the individual's body weight is supported (e.g., weight machines with pulleys) to safely reinforce proper technique is recommended. In support of this concept, obese youth (aged 6–13 years) reported increased enjoyment and confidence in PA after participation in a resistance training program (Pescud et al. 2010).

Currently available evidence recommends a combination of aerobic and resistance-type exercises (Davis et al. 2011; Maziekas et al. 2003). Aerobic training combined with resistance training had a greater effect on maintenance of a lower body fat percentage 1 year after intervention compared with aerobic training alone (Maziekas et al. 2003). Participation in the "New Moves" multidisciplinary intervention (the PA component of which included a combination of aerobic and resistance exercise 4 days per week for 16 weeks) resulted in increased enjoyment of PA for overweight girls in grades 9 to 12 (Neumark-Sztainer et al. 2003). For more vigorous exercise sessions, circuit training in short bouts of alternating aerobic and resistance exercise may be perceived as more enjoyable and sustainable when exercise tolerance could be an issue. Circuit training has been associated with decreases in abdominal fat and increases in fitness and insulin sensitivity in a sample of overweight and obese Hispanic adolescents (Davis et al. 2011). In summary, PA interventions in obese youth should incorporate a variety of activities that are progressive and enjoyable.

4. The role of the parent–guardian should be considered

Parents–guardians can have an important influence on their children's health behaviours. The importance of parental involvement in the promotion of PA and healthy eating is demonstrated by a study by Golan et al. (1998). This randomized longitudinal prospective study found that overweight children aged 6 to 11 years of parents who were targeted as the exclusive agents of change (i.e., only parents participated in the support and education group sessions) lost more weight and were 9 times less likely to drop out than when the child was targeted as the only agent of change. Notably, these effects were maintained at the 7-year follow-up (Golan and Crow 2004).

Some parent–guardian factors such as parental age and academic education level, which are known to influence PA behaviours in youth, are less likely to change than others. Nevertheless, these less modifiable factors should be identified because they may be potential barriers to PA participation for children. For example, having older parents was found to be negatively correlated with the PA level of preschoolers (Zecevic et al. 2010). There is a positive association between the PA levels of parents and their children (for boys aged 4–12 years) (Van Der Horst et al. 2007), and children were more likely to be active if their parents perceived PA as highly enjoyable (Zecevic et al. 2010). Higher parental BMI predicted attrition from a weight-control trial for obese adolescents aged 13 to 16 years (Jelalian et al. 2008). Additionally, parental academic education level was found to be positively associated with level of PA in adolescents (Van Der Horst et al. 2007).

Parental support has been associated with higher PA levels in preschoolers (Zecevic et al. 2010) and children (Van Der Horst et al. 2007). Preschool-aged children were 6.3 times more likely to be highly active if they received greater parental support (Zecevic et al. 2010). The PA level in adolescents is positively associated with “family influences” (Van Der Horst et al. 2007). Parents reinforce and model healthy behaviours (Rhee et al. 2011) and can change the setting in which their child lives (Golan et al. 1998). Parental encouragement or decision was identified as a main factor in the initiation of a resistance-training program for overweight youth (Pescud et al. 2010).

Parental support can be intangible or tangible (Beets et al. 2010; Deforche et al. 2011). For intangible support, parents serve to model PA, encourage their children, and reinforce positive PA behaviours (Huang et al. 2009; Rhee et al. 2011). Transportation and paying for programs and equipment are the most obvious forms of tangible support for PA. Lack of such tangible support could be a major barrier to PA for some families. For example, in the GEMS intervention, transportation was a barrier to participation in afterschool dance classes for 8- to 10-year-old girls (Robinson et al. 2003). Similarly, parents identified the cost of a resistance-training program for overweight and obese children aged 6 to 13 years as a barrier to continuing participation (Pescud et al. 2010). A systematic review found that parent payment of fees and (or) equipment was positively associated with the measured PA of children and adolescents (Beets et al. 2010), highlighting the importance of tangible support by parents in the promotion of PA in their children.

The age of the participant should be considered when determining the level of parent–guardian involvement in the PA program. Parent–guardian perceptions, opinions, and time constraints, as well as the accessibility and time demands of the intervention, should be taken into account when designing a PA intervention. To optimize parent–guardian influence on the children's and adolescents' adherence to the PA intervention, parent–guardian barriers should be identified and appropriate solutions developed, and more modifiable factors could be targeted as part of the intervention.

5. Individual physical and psychosocial characteristics should be accounted for

It is suggested that the success of a PA intervention may depend on how well it is tailored to the individual (Deusinger 2012) since both physical and psychosocial characteristics influence PA behaviours (Pimenta 2010; Sherwood and Jeffery 2000; Sothern et al. 1999*a*).

5.1. Physical characteristics

Correlates of PA are different for children and adolescents (Sallis et al. 2000; Van Der Horst et al. 2007). The participants' physical size, age, race–ethnicity, and sex can all influence PA behaviours. Controlling for age and weight, the dropout rate from a 1-year PA intervention in obese youth (7–17 years) was greater for boys than for girls, greater for black participants than for white participants, and greater for those classified as moderate and severely obese than for those classified as mildly obese (Sothern et al. 1999*a*). It is important to consider the physical size and capabilities of participants; Seidler et al. (1993) state that exercise equipment and facilities should be designed to meet the needs of populations such as children and obese individuals to prevent injury and so that participants receive the full potential benefits of PA. Overall, PA levels are greater in males than in females during childhood and adolescence (Gortmaker et al. 2012; Molnar and Livingstone 2000; Sallis et al. 2000; Van Der Horst et al. 2007). However, PA levels decrease with age (Gortmaker et al. 2012; Molnar and Livingstone 2000; Sallis et al. 2000) in both sexes, with the largest declines seen in adolescent girls (Butt et al. 2011; Molnar and Livingstone 2000), making PA intervention and programming especially important for this population.

When comparing overweight boys and girls (aged 9–13 years), it was found that motivation among girls for starting a resistance-training program was related more to general health improvement, whereas motivation for boys to begin the program was related to performance and strength outcomes (Pescud et al. 2010). Pescud et al. (2010) reported that continued participation for girls was attributed to the social aspects of the program (making friends with other participants, bonding with their trainer). Butt et al. (2011) found that boys aged 13 to 16 years participated in PA for the physical results (getting sweaty, feeling tired), whereas girls were motivated by improved body image and by the popularity associated with PA participation. Moreover, “New Moves”, an afterschool PA intervention targeting overweight girls (grades 9–12) or those at risk of becoming overweight, was successful in increasing the participants' self-worth (Neumark-Sztainer et al. 2003).

Race–ethnicity may also influence PA levels and obesity. Prevalence of overweight among children aged 6 to 19 years was found to be greater in African-American and Mexican-American youth compared with Caucasian youth (Hedley et al. 2004). It has been suggested that different cultural views can influence individual perceptions of obesity (Wheeler et al. 2012). For example, African-American girls report less body dissatisfaction compared with white girls (French et al. 1997). Greater dropout from a PA intervention for weight loss was reported in black children than in white children (aged 7–17 years) (Sothern et al. 1999*a*). Understanding the individual variables and motives related to initiation of, participation in, maintenance of, and dropout from PA programs is important when tailoring a program to increase adherence.

5.2. Psychosocial characteristics

Greater depression has been associated with lower levels of PA in children and adolescents (Sallis et al. 2000). Having a higher delinquency score (measured with the Child Behaviour Checklist) predicted dropout within 3 months of a lifestyle intervention for obese children (de Niet et al. 2011). Increased autonomy may positively affect PA behaviour and can be accomplished by offering opportunities to master new skills, supporting participants' choices, and giving children the knowledge and skills to be physically active (Deforche et al. 2011). Different predictors of dropout were identified at different stages of a lifestyle intervention for obese children (de Niet et al. 2011), demonstrating the importance of continually monitoring individual characteristics throughout the intervention to avoid dropout. Questionnaires assessing stage of change (which has been related to individuals' perceptions of PA (Marshall and Biddle 2001)) and including a run-in program could help identify participants who have a better chance of adhering to the PA program or who are at a higher risk of dropout. Assessing the participant's stage of change can help identify his or her risk of attrition and can help individualize the intervention to facilitate the participant's readiness for change. Personal factors that predispose the participant to dropout should be addressed prior to commencing any PA program (see section 9).

In physical education settings, increasing the opportunities for PA and offering a variety of options while being cautious of obesity bias (Rukavina and Li 2008) is paramount to increasing levels of PA in all children and adolescents. Because of the controlled nature of research interventions, however, recommendations made in this section may be more difficult to implement depending on the objective of the study. A study that compared different exercise modes (swimming, water games, cycle ergometry, strength training and (or) stability circuit training, small group games–relays, and team sports) in a sample of 20 obese adolescents found that energy expenditure was comparable among different activities (Thiel et al. 2011). Thus, the authors suggest individualizing programs according to the participant's preferences to maximize adherence.

To promote exercise program adherence, interventions should be tailored to the individual's physical (size, age, race–ethnicity, and sex) and psychosocial (personality traits, autonomy, perceptions of PA, and stage of change) characteristics, as well as to the individual's preferences.

6. Realistic goals should be set

Goal setting is an effective behavioural change technique employed in PA interventions for overweight youth (Faith et al. 2012; Williams and French 2011). Specific, short-term, and measureable goals should be established with the child or adolescent (Huang et al. 2009). By offering youth the opportunity to take ownership of their involvement, goals promote self-efficacy and (or) autonomy. Interventions focusing on increasing the autonomy of overweight youth may increase adherence to an exercise program and level of PA (Deforche et al. 2011). Showing visual representations of individual progress such as journal logs, medical charts, and diagrams could be useful in measuring progress, giving feedback, and establishing future goals. Providing incentives for continued participation is recommended; however, effort and participation should be emphasized more than skill mastery, to increase self-efficacy and associated PA level (Deforche et al. 2011; Williams and French 2011). Using incentives and positive reinforcement in the form of praise and encouragement is particularly effective in increasing PA and health behaviour change in preadolescent children (Goldfield et al. 2002).

7. Regular reminders should be offered

Commitment to PA programs is a time-sensitive issue. A major barrier to PA participation in adolescents (aged 13–16 years) was time (Butt et al. 2011). Individuals responsible for implementation of exercise programs should recognize that participants may have other commitments that take priority over PA participation and should provide reminders to promote adherence. Those who develop PA programs should take advantage of the rapidly changing breadth of online social media options (e-mail, blogs, Facebook, Twitter, text messaging, instant messaging, cell phone applications, etc.) and should establish the participants' preferred methods of communication prior to commencing the intervention. Although research suggests that social support (Dowda et al. 2007; Salvy et al. 2009) increases overweight youth's motivation to be physically active, there is a lack of evidence to support the use of social media to increase compliance to PA in youth. A systematic review by Nguyen et al. (2011) suggests that most studies are of poor quality, and 87% of the studies that incorporated electronic interventions into the prevention and treatment of obesity in youth have not evaluated the effects of the electronic intervention separately from the other components of the intervention. More recently, Facebook was shown to be an effective tool for recruiting participants and decreasing loss to follow-up in a large sample of adolescent girls in the Trial for Activity in Adolescent Girls (TAAG) (Jones et al. 2012). A review by Vandewater and Denis (2011) suggests that with the ever-growing popularity of social media among youth, social networking as a means of increasing adherence to health behaviours should be explored further. To our knowledge, no studies have examined the influence of social networking sites (e.g., Facebook, MySpace, LinkedIn, Twitter, etc.) on adherence to PA interventions in obese youth and thus, further investigation is needed. Program developers should capitalize on the ever-growing popularity, cost effectiveness, feasibility, and potential of social networking as a means of increasing social support to promote PA adherence. Providing regular reminders through their pre-established preferred method of communication may help increase attendance at training and (or) testing sessions. Reminders should be given 1 or 2 days before the scheduled session, and follow-up contact can be useful 1 or 2 days after their last session to reinforce their positive behaviour and thank them for attending.

8. A multidisciplinary approach should be taken

Obesity is a complex condition with multifactorial causes linked to the obesogenic environment we live in (Chaput et al. 2012). Incorporating a multidisciplinary approach is a key strategy for the successful prevention, management, and treatment of pediatric obesity and, importantly, its comorbidities (Bryan et al. 2010).

From our experience, a team of well-qualified empathetic professionals consisting of exercise specialists, dietitians, endocrinologists, and psychologists may enhance the success of a pediatric PA program. It is clear that the psychological impact of obesity on children and adolescents is widespread, showing evidence of body dissatisfaction, low self-esteem, depression, disordered eating habits, social stigma, and decreased quality of life (Vander Wal and Mitchell 2011). Having a psychologist on the team is vital to the success of a PA program, as is keeping in regular contact with participants to establish a rapport and to help resolve PA adherence issues related to psychological health as soon as they arise (Epstein and Goldfield 1999; Epstein and Wing 1980). Motivational interviewing is one of many widely used and empirically supported psychological techniques designed to peak motivation and readiness for change (Erickson et al. 2005). A meta-analysis of randomized controlled trials found that motivational interviewing for increasing PA had a positive effect in 8 of the 10 relevant studies (Rubak et al. 2005). Use of a multidisciplinary health care team allows comprehensive, ongoing evaluation and adjustment

Table 1. Summary of the top 10 practical lessons learned from PA interventions with overweight and obese children and adolescents.

Lesson	Recommendations	Age group	Key references
1. PA setting–context is important			
1.1. Physical environment	Maximize accessibility	C and A	Sallis et al. 2000; Dunton et al. 2009
	Use portable and multiuse equipment	C	Dowda et al. 2009
	Incorporate music	C and A	De Bourdeauduij et al. 2002; Adamo et al. 2010
1.2. Sociocultural environment	Reinforce intrinsic more than extrinsic motivators	A	Deforche et al. 2011; Gillison et al. 2011
	Consider group-based PA (offer same-sex option for children and adolescents undergoing puberty)	C and A	Salvy et al. 2012; Bruner and Spink 2011; Wilson et al. 2012; Strauss 2000; Neumark-Sztainer et al. 1998
	Offer a choice of activities	C and A	Stankov et al. 2012
2. Choice of fitness trainer matters	Ensure trainer makes friendly introductions among all staff and participants	C and A	Deforche et al. 2011
	Ensure trainer familiarizes participants with equipment	C and A	Deforche et al. 2011
	Ensure trainer treats participants as equals and develops friendships	C and A	Deforche et al. 2011; Pescud et al. 2010
	Consider participant preference in the sex of trainer	Pubescent C and A	Drummond et al. 2007
	Ensure trainer has knowledge of PA and the multifactorial complexity of obesity and avoids stereotypes and stigma	C and A	Puhl and Heuer 2009
	Ensure trainer communicates effectively with youth and has empathy, enthusiasm, patience	C and A	
	Consider including peer training	C and A	Cui et al. 2012; Shah et al. 2011; Stock et al. 2007; DeBar et al. 2011
3. Physical activities should be varied and fun	Use a variety of exercises depending on participant's preferences	C and A	Deforche et al. 2011
	Offer easily mastered and progressive activities	C and A	Sothern et al. 1999*a*
	Aerobic training: less weight-bearing at the beginning	C and A	Deforche et al. 2003
	Resistance training: supervised, progressive, and age specific	School-aged C and A	Faigenbaum et al. 2009; Bernhardt et al. 2001; Sothern et al. 1999*b*
	Circuit training: short bouts of exercise (include a combination of resistance and aerobic exercises)	School-aged C and A	Davis et al. 2011; Maziekas et al. 2003
4. The role of the parent–guardian should be considered	Consider intangible support: parental habits and perceptions of PA	C and A	Rhee et al. 2011; Huang et al. 2009
	Consider tangible support: cost and fees, proximity and location, and transportation	C and A	Beets et al. 2010; Robinson et al. 2003; Pescud et al. 2010
5. Individual physical and psychosocial characteristics should be accounted for			
5.1. Physical characteristics	Address personal factors that can predispose to dropout	C and A	Sallis et al. 2000; Van Der Horst et al. 2007
	Consider participant's size, age, race–ethnicity, and sex	C and A	Seidler et al. 1993
	Understand participant motivators for initiation and participation in PA, and monitor continuously throughout the program	C and A	Pescud et al. 2010; Butt et al. 2011
5.2. Psychosocial characteristics	Consider participant personality traits, autonomy, perceptions, and preferences for PA	C and A	Sallis et al. 2000; de Niet et al. 2011; Deforche et al. 2011; Thiel et al. 2011
6. Realistic goals should be set	Set specific, short-term, measureable goals	C and A	Huang et al. 2009
	Use journal logs, charts, diagrams to offer feedback on progress	C and A	
	Provide incentives for continued participation and emphasize effort and participation (not outcomes only)	C and A	Deforche et al. 2011; Williams and French 2011
	Offer praise and encouragement	C and A	Goldfield et al. 2002

Table 1 (*concluded*).

Lesson	Recommendations	Age group	Key references
7. Regular reminders should be offered	Recognize that participants have other priorities and commitments	C and A	
	Consider using social media	C and A	Nguyen et al. 2011; Jones et al. 2012; Vandewater and Denis 2011
	Use participant's preferred method of communication	C and A	
	Send reminders 1 or 2 days before scheduled session, make follow-up contact 1 or 2 days after session	C and A	
8. A multidisciplinary approach should be taken	Develop a comprehensive, ongoing program evaluation and adjustment	C and A	Bryan et al. 2010
	Use a team of exercise specialists, dieticians, endocrinologists, and psychologists	C and A	Epstein and Goldfield 1999; Epstein and Wing 1980
	Consider using motivational interviewing	C and A	Erickson et al. 2005; Rubak et al. 2005
9. Barriers should be identified early and a plan to overcome them developed	Consider biological, familial, behavioral, social, and environmental barriers	C and A	Abraham and Michie 2008; Dumith et al. 2012; Brennan et al. 2012
	Realize that overweight and obese youth perceive more barriers to PA than do their nonoverweight peers	C and A	Stankov et al. 2012
	Use interviews and questionnaires at start of program to identify barriers	C and A	Marshall and Biddle 2001
	Address barriers and find solutions in collaboration with participant	C and A	
	Continually evaluate barriers throughout the program	C and A	
10. The right message should be communicated: what's in it for them?	Outline realistic expectations	C and A	
	Communicate purpose and outcomes in a meaningful way	C and A	
	Realize that every participant is different and tailor the intervention to the individual	C and A	Deusinger 2012

Note: PA, physical activity; C, children, A, adolescents.

of the intervention to allow better tailoring to the participants' needs.

9. Barriers should be identified early and a plan to overcome them developed

Early barrier identification is an effective technique for monitoring adherence in PA interventions (Abraham and Michie 2008). Change in PA levels from childhood to adolescence is influenced by social, familial, biological, behavioural, and environmental factors (Dumith et al. 2012), all of which may function as barriers to PA and program adherence. Based on qualitative analyses of barriers, it was suggested that overweight youth perceive more barriers to PA participation than do other youth (Stankov et al. 2012). To engage overweight adolescents in PA, the barriers preventing their participation must first be addressed (Stankov et al. 2012). An attrition analysis of a family-based cognitive behavioural lifestyle randomized controlled trial of overweight and obese adolescents and their parents identified parent and adolescent barriers to program completion (Brennan et al. 2012). The authors recommended increasing adolescent motivation, decreasing intervention requirements, and establishing a convenient location and flexible schedule around holidays and family commitments to promote participation (Brennan et al. 2012). Questionnaires and (or) interviews with participants may be conducted prior to the intervention to identify individual barriers and to plan PA dropout prevention strategies. Once these barriers are identified, the team needs to address them and help the child and (or) family overcome them with continual evaluation throughout the intervention. The 10 recommendations we outline in this manuscript provide practical strategies to minimize the greatest barriers to PA participation for overweight and obese youth.

10. The right message should be communicated: specifically, what's in it for them?

Family-centered care is of the utmost importance in the successful design of any PA program (Farnesi et al. 2011). Children and adolescents and their families are dedicating their limited free time to participate in a PA program in which expected weight loss, fitness, and (or) health benefits and outcomes may not be realistic. As soon as the participant shows interest in the study, he or she should be made aware of the potential physical and (or) psychological benefits they may acquire from participation in the program. However, realistic expectations (both short and long term) and conditions of participation for optimal results should also be outlined to deter from dropout. For example, higher rates of weight loss at the beginning of an exercise intervention were associated with lower dropout rates in obese youth (aged 7–17 years) participating in an exercise intervention (Sothern et al. 1999*a*). Epstein et al. (1984) also showed the highest weight loss in participants with high adherence to the PA intervention.

Communicating the purpose and outcomes of the intervention should also be done in a way that is meaningful to the participant. For example, telling younger, elementary school-aged children that they will improve their fitness may not be as encouraging as saying they will be able to play outside on the playground with their friends for longer without feeling as tired. This will allow a sense of personal fulfillment so that the participants understand that these PA programs are conducted to enhance their health and well-being.

Significance

One of the most paramount lessons we learned from our practical experience in implementing PA interventions in the pediatric population is the importance of identifying individual barriers to participation early and of addressing them prior to commencing the program. Even if all the participants are considered inactive and overweight or obese at baseline, barriers could be different among individuals. It is important to address these deeper personal and societal issues; otherwise, the short-term PA intervention alone may not result in long-term benefit if these changes are not feasible or sustainable for the individual.

Although our recommendations to increase adherence stem from our research experience with PA interventions in overweight and obese youth, we believe that the lessons we learned are practical for educators, exercise specialists, parents, researchers, and policy makers. The recommendations in this paper can be applied to other pediatric PA programs, physical education settings, and public health programs with the hope of decreasing attrition and increasing the benefits of PA participation for promoting health in children and adolescents.

Conclusion

Lack of adherence to and long-term maintenance of PA in overweight and obese children and adolescents is of great concern. This paper reviewed 10 practical recommendations for maximizing participation and health outcomes of PA programs for overweight and obese children and adolescents. The setting of the intervention should be at an accessible location with a respectful and welcoming environment and should offer the option of group exercise sessions. Trainers have a great influence on the participants' attitudes and PA beliefs, and as such, they should be chosen with care. They should be knowledgeable, skilled, and empathetic. Physical activities prescribed should be varied and in line with the participants' preferences to increase motivation. Based on adherence rates, low-intensity aerobic exercise and resistance training may be preferable exercise modalities for overweight and obese children and adolescents. When possible, interventions should be tailored to an individual's physical and psychosocial characteristics. The participants' physical size, age, and sex may determine the equipment usage, choice of activities within the program, trainer characteristics, and level of parent or guardian involvement. It is crucial to assess and involve parents and guardians in programs, especially for younger children. Monitoring progress and providing regular and individual feedback are important. To accomplish this, participants should be assisted to develop specific and measurable goals. Participants should also be assisted in identifying potential barriers and in developing a plan to overcome these barriers. A multidisciplinary team is recommended to provide comprehensive and continuous individual evaluation and program adjustment. A family-centered approach should be taken, and the purpose and realistic potential outcomes of the intervention should be explained simply and effectively to the participants.

This paper serves as a guide to exercise specialists, exercise facility managers, clinicians, future investigators, and policy makers, offering practical advice on designing programs to increase adherence and continuation of PA to optimize the physical, psychological, and social health benefits of adopting a more active lifestyle in overweight and obese children and adolescents. Our 10 practical recommendations are summarized in Table 1. Although some of our recommendations may be more feasible in some settings than in others (e.g., physical education program vs community-based or public health program vs a randomized controlled research trial), efforts should be made to tailor the PA intervention to the individual, to maximize adherence. We hope that the recommendations listed in this paper will help health professionals in various settings increase adherence to and sustainability of PA in children and adolescents.

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Conclusion

The results of this thesis improved our understanding of the effects of different exercise training modalities on body composition, cardiovascular disease risk markers, resting metabolic rate and fitness in overweight and obese adolescents. This dissertation has great public health implications for future design and implementation of more effective exercise programs to improve the overall health of adolescents with obesity and outlines future research directions in this population group.

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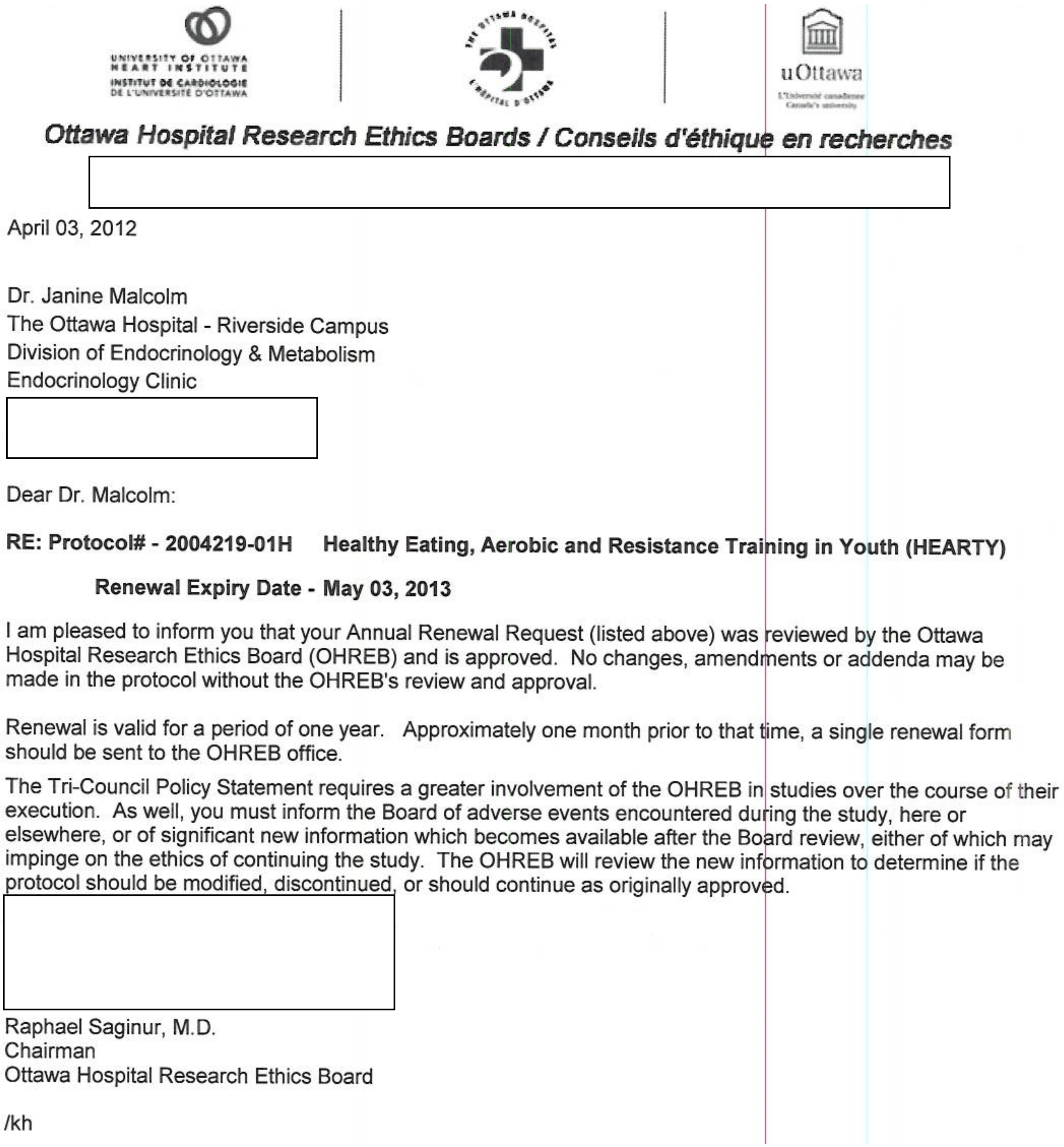
APPENDIX

Ethical Approvals



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Ottawa Hospital Research Ethics Boards / Conseils d'éthique en recherches

[redacted]

April 03, 2012

Dr. Janine Malcolm
The Ottawa Hospital - Riverside Campus
Division of Endocrinology & Metabolism
Endocrinology Clinic
[redacted]

Dear Dr. Malcolm:

RE: Protocol# - 2004219-01H Healthy Eating, Aerobic and Resistance Training in Youth (HEARTY)

Renewal Expiry Date - May 03, 2013

I am pleased to inform you that your Annual Renewal Request (listed above) was reviewed by the Ottawa Hospital Research Ethics Board (OHREB) and is approved. No changes, amendments or addenda may be made in the protocol without the OHREB's review and approval.

Renewal is valid for a period of one year. Approximately one month prior to that time, a single renewal form should be sent to the OHREB office.

The Tri-Council Policy Statement requires a greater involvement of the OHREB in studies over the course of their execution. As well, you must inform the Board of adverse events encountered during the study, here or elsewhere, or of significant new information which becomes available after the Board review, either of which may impinge on the ethics of continuing the study. The OHREB will review the new information to determine if the protocol should be modified, discontinued, or should continue as originally approved.

[redacted]

Raphael Saginur, M.D.
Chairman
Ottawa Hospital Research Ethics Board

/kh

Children's Hospital of Eastern Ontario
Centre hospitalier pour enfants de l'est de l'Ontario

CHEO Research Ethics Board ANNUAL RE-APPROVAL NOTICE

Principal Investigator	Dr. Stasia Hadjiyannakis
REB Protocol Number	05/04E
Protocol Title	Healthy Eating, Aerobic and Resistance Training in Youth (HEARTY)
Department or PSU	Endocrinology
Approval Date	February 28, 2012
Approval Valid Until	**February 15, 2013**
Date for Submission for Next Annual Renewal Report	**January 15, 2013**
Documents Reviewed & Approved	▪ Reporting Form – Annual Renewal (January 25, 2012)

This is to notify you that the CHEO REB has granted approval to the renewal for the above named research study for a period of one year. The renewal was reviewed and approved by the Chair only. Decisions made by the Chair under delegated review are ratified by the full Board at its subsequent meeting.

In fulfilling its mandate, the CHEO REB is guided by: Tri-Council Policy Statement; ICH Good Clinical Practice Practices: Consolidated Guideline; Applicable laws and regulations of Ontario and Canada (e.g., Health Canada Division 5 of the Food and Drug Regulations & the Food and Drugs Act - Medical Devices Regulations).

Approval is granted with the understanding that the investigator agrees to comply with the following requirements:

- The investigator must conduct the study in compliance with the protocol and any additional conditions set out by the Board.
- The investigator must not implement any deviation from, or changes to, the protocol without the approval of the REB except where necessary to eliminate an immediate hazard to the research subject, or when the change involves only logistical or administrative aspects of the study (e.g., change of telephone number or research staff). As soon as possible, however, the implemented deviation or change, the reasons for it, and, if appropriate, the proposed protocol amendment(s) should be submitted to the Board for review.
- The investigator must, prior to use, submit to the Board changes to the study documentation, e.g., changes to the informed consent letters, recruitment materials. Should major revisions to the consent form be made, the investigator agrees to re-consent those subjects who have originally consented to the study and who wish to continue on the study.
- For clinical drug or device trials, investigators must promptly report to the REB all adverse events that are both serious and unexpected (SAEs). For SAE reports on CHEO patients, the investigator must also comply with the hospital-wide Policy regarding, Procedures For Considering Medical Error In The Differential Diagnosis of Severe Adverse Events (SAE) Associated with the Drugs Administered in a Clinical Trial (see http://cheonet/data/1/rec_docs/3792_Medical%20Error%20Policy%20revised%20january%2020061.doc).
- For all other research studies, investigators must promptly report to the REB all unexpected and untoward occurrences (including the loss or theft of study data and other such privacy breaches).
- Investigators must promptly report to the REB any new information regarding the safety of research subjects (e.g., changes to the product monograph or investigator's brochure for drug trials). Where available, any reports produced by Data Safety Monitoring Board should be submitted to the REB.
- Investigators must notify the REB of any study closures (temporary, premature or permanent), in writing along with an explanation of the rationale for such action.

- Investigators must submit an annual renewal report to the REB 30 days prior to the expiration date stated on the final approval letter.
- Investigators must submit a final report at the conclusion of the study.
- Investigators must provide the Board with French version of the consent form, unless a waiver has been granted.

[redacted]

Dr. Carole Gentile, C.Psych.
Chair, Research Ethics Board

Consent Form & Information Sheet

Consent Form and Information Sheet:
Healthy Eating, Aerobic and Resistance Training in Youth: (HEARTY)

You have been asked to take part in a research study at the Ottawa Hospital, Riverside Campus and the Children's Hospital of Eastern Ontario. This study is carried out under the supervision of Drs. Ronald Sigal, Janine Malcolm, Stasia Hadjiyannakis, Gary Goldfield and Glen Kenny. The purpose of the study is to look at the effects of different types of exercise on people aged 14 to 18 years old that are overweight.
In this 12 month study, after a 4-week "Starter Period" (see below), you will be randomly chosen (like pulling a name out of a hat) for one of 4 groups. The four groups are: the diet and aerobic exercise group, the diet and resistance exercise group, a diet and combined aerobic and resistance exercise group, or to a diet-only group. **Aerobic training** is forms of exercise that increase heart rate and lung capacity. Examples of aerobic exercise are brisk walking, cycling, and jogging. **Resistance training** is forms of exercise that use muscle strength to move a weight. Examples are exercises with dumbbells and barbells and or weight machines. When done often enough and with proper intensity, resistance training increases muscle strength and size.

PROCEDURE
Before starting in the study you will have a medical history, physical examination and some laboratory tests. This is to make sure that you are suitable for the study. You will also have to do a treadmill VO_2 max test; and an MRI scan before joining the study. These tests measure body fat and the amount of energy your body uses at rest. Here is some more information about these tests.

Oral Glucose Tolerance Test:

The glucose tolerance test measures the body's ability to use sugar. After not eating for 12-hours (an overnight fast), you will drink a sweet glucose solution. Blood will be taken before drinking the solution and again 2 hours after drinking the solution. This test is performed in the morning and will take about 2 ½ hours.

Treadmill VO_2 Max Test:

This test involves walking faster and faster on a treadmill until you are too tired to continue. Your nose will be plugged, and you will breathe through a mouthpiece connected to a machine. The machine will measure the amount of certain gases in the air you breathe in and out. You will also wear a chest strap that will check your heart rate during the test. The test will last about 10 to 15 minutes.

MRI scan

A magnetic resonance imaging scan, or an MRI, uses a strong magnetic field and radio waves to produce very clear and detailed pictures of the inside of the body on a computer. MRI is a very safe and painless procedure. You will be asked to remove all metal and electronic devices from your clothing and body before the exam (such as watches, jewelry, cellular phones, and credit cards). This protects your valuables from the effects of the MRI machine. You may be asked to change into a hospital gown to ensure that there is no metal on your clothing (such as snaps and zippers). You will lie on a table face-up and slowly be entered into the scanner, which looks like a large tube. You will be asked to stay very still during the scan. The scan will last 30-60 minutes. The MRI centre is located at 61 Ave. Laurier in Gatineau, Quebec.

Resting Metabolic Rate

Energy used at rest (resting metabolic rate) will also be measured. During the test, you will sit in a chair and breathe through a mouthpiece connected to a computer. The computer will measure the amount of certain gases in the air you breathe in and out. You will wear a nose clip so that no air escapes through your nose, and you will be asked to stay awake and to move as little as possible during the test. This test will take about 30 to 45 minutes and must be performed in the morning.

Pedometer log

A pedometer is a small device (smaller than a pager) used to measure the number of steps you take during the day. You will be issued a pedometer during your Resting Metabolic Rate appointment. We will ask you to wear your pedometer for 7 days (all day) at the beginning of the study and then again for 7-days at the 3-month, 6-month and 12-month points in the study.

Starter Period

Once it has been decided that you qualify for the study and you have finished all of the screening tests, you will begin a 4-week starter program. You will be asked to go to at least four exercise sessions a week at one of the following gym facilities:

1. Orleans YMCA-YWCA, located at 265 Centrum Blvd;
2. Nepean YMCA-YWCA, located at 1642 Merivale Rd (in the Merivale Mall);
3. Kanata YMCA-YWCA, located at 1000 Palladium Dr (at Scotia Bank Place);
4. RA Centre, located at 2451 Riverside Dr (beside the Billings Bridge Mall).
5. Nautilus Plus, located at 920 Blvd Maloney West, Gatineau
6. Nautilus Plus, located at 425 Blvd Saint-Joseph, Hull

You will be given a free membership card to only one of these gyms. An exercise specialist will help you get used to the gym and exercise equipment. You will be taught how to use each exercise machine. On your first visit to the gym you will have to do a strength test. A strength test measures the most weight you can lift 10 times on each of the weight machines. This test will be repeated in the gym at 3, 6 and 12 months and takes approximately 25 minutes. You will meet with either the exercise specialist or a volunteer trainer 2x/week during the starter period, and you will do the other 2 workouts on your own within that week. During this part of the study, you will do 15-20 minutes of aerobic exercise (such as walking) at all four weekly visits. You will also do about 20 additional minutes of resistance exercise (using weight machines) at all four weekly visits. You will complete logs of your exercises. The exercise specialist will look at your logs and attendance regularly. They will follow-up by telephone or meet with you in person to talk about any problems.

The volunteer trainers are supervised by the Exercise Specialist and are highly qualified. They are University of Ottawa students in the Human Kinetics program and have completed additional training in pursuit of their Personal Fitness and Lifestyle Consultant (PFLC) certification. They are also certified in Standard First Aid and CPR and know what to do in case of an emergency.

Only people who attend at least 13 of the 16 exercise sessions during the Starter Period will be allowed to continue in the study.

Supervision of your diet: During the starter period and again at 3, 6 and 12 months, you will write down everything that you eat for three days. At a separate appointment, a dietitian, will look at your food list and provide you with comments on your diet. The dietitian will review your energy needs and will make suggestions to improve your diet. This visit will take about 30 to 60 minutes. You will also receive phone calls at 1.5 and 4 months, for support, review of dietary goals and so you may report on any lifestyle

changes.
During the "Starter period" you will attend two one-hour small group sessions offered on different topics such as: taste testing of fruits and vegetables; menu planning; healthful snacks;; and healthier eating at fast food outlets.

Randomization
If you go to at least 13 of the 16 scheduled exercise sessions during the Starter Period, you will be allowed to continue in the study. You will be **randomly chosen for one of the three diet and exercise groups or the diet-only group**. Randomization means that you are put into a group by chance. You or the research staff can not choose the group you will be in. You will have an equal (one in four) chance of being placed in any group.
If you are randomized to one of the exercise groups you will be given 5 additional months of membership at the YMCA/YWCA or RA Centre. If you finish all testing and go to at least 70% of the exercise sessions you will be given an extra 6-month gym membership for free. At each of the visits to the gym, your membership card will be scanned to check your attendance and you will sign into the HEARTY Binder at the front desk.

In all of the exercise groups, you will exercise at the gym 4 times per week as described below and complete logs of your exercises. You will work with the exercise specialist or a volunteer trainer 1x/week and you will complete 3 workouts/week on your own. You can choose the day and time of these 3 workouts. The exercise specialist will look over your exercise logs and attendance regularly. They will follow up by telephone or meet with you in person to talk about any problems.

(1) The **diet and aerobic exercise group** will be given an exercise program involving 4 exercise sessions per week. If you are placed in this group you will advance slowly until you reach 45 minutes of aerobic exercise. You will have the choice of switching between aerobic exercise machines such as a treadmill or bicycle. You will be asked to wear a special watch and chest strap while doing the aerobic exercise so that you can check your heart rate. You will be asked not to do any resistance exercise (weight lifting) for the next 22 weeks.

(2) The **diet and resistance exercise group** will be given an exercise program involving exercise with weight machines. If you are placed in this group you will complete two to three sets of 8 to 20 repetitions of each resistance exercise included in your routine. You will slowly increase the amount of weight for each exercise. For the next 22 weeks you will be asked not to do more walking or aerobic type exercise than you did before starting the study. Each resistance exercise session will last from 30-45 minutes.

(3) The **combined aerobic and resistance training group** will be given both exercise programs as described in (1) and (2) for 22 weeks after the completion of the starter period. Both types of exercise will be done at the gym on the same days. Since the aerobic and resistance exercise routines each last 30-45 minutes, the total amount of time spent exercising at each session will be up to 90 minutes if you are randomly chosen for this group.

(4) In the **diet-only group,** you will be asked to exercise only as much as you did before entering the study for the next 22 weeks. During this time, a dietitian will give you the same guidance with your diet as the other people in the study. At the end of the 22 weeks, you will be given the combined aerobic and resistance exercise program for 6 months, as described above.

Clinic Visits

All participants in the study (in the diet and exercise groups and diet-only group) will be examined in clinic 3, 6 and 12 months after starting the study. At each visit you will be asked about your smoking history, diet history, physical activity level and major medical events. You will be asked to complete questionnaires which will be used to measure the psychological effects of aerobic and resistance training. The questionnaires will be given and completed during the oral glucose tolerance test at baseline and 6-months and will include factors such as body image, self-esteem, quality of life, mood, eating attitudes and behaviour, and personality characteristics. Your weight, waist & hip circumference and blood pressure will be measured. Clinic visits will take about 30 to 35 minutes and will be performed in the early morning. Blood samples and a urine sample will be taken for laboratory tests. The amount of blood taken at each visit will be about 50ml or 3 ½ tablespoons. The maximum amount of blood drawn over the year in the study will be about 200 ml (~13 tablespoons; equal to a little less than half of one blood donation). We would like your permission to store some of your blood for future testing. In the future, there might be substances that are discovered that would predict a person's risk of heart disease, diabetes etc. The research staff may be able to look at your blood to determine if exercise and diet have an effect of this substance.

Do you agree to have some blood samples stored for future research related to physical activity and diet in overweight youth? YES____NO____

An MRI scan, treadmill VO_2 max test and resting metabolic rate, (as described above) will be repeated 6 months after you enter the study to see how fat, muscle and overall physical fitness, have changed.

SUBJECT DESCRIPTION

340 youth will be asked to participate in this research study.

To make sure that it is safe and appropriate to participate you must meet the inclusion/exclusion criteria outlined in Table 1.

Table 1 Inclusion/Exclusion Criteria

Inclusion criteria
• Male or female; aged 14-18 years • Later stages of puberty development • Overweight for your age and gender • Larger waist circumference for your age and gender
Exclusion criteria
• Participation in a regular exercise program over the past 4 months • Diagnosed with Diabetes. • Body weight over 159 kg, and/or BMI>45 kg/m^2 • Use of any performance-enhancing medication. • Lose or gain a large amount of weight in the past 2 months • Uncontrolled high blood pressure (BP >150 mm Hg systolic or >95 mm Hg diastolic) • Medical conditions that make physical activity difficult or unsafe • Other illness judged by the patient or study physician to make participation in this study not recommended • Not willing or not available to attend exercise and/or nutrition visits at scheduled times and locations • Unable to understand or follow instructions. • Pregnancy at the start of the study, or intention to become pregnant in the next year. • Unable to communicate in English or French • Unwillingness of subject and/or parent/guardian to sign informed consent.

RISKS AND DISCOMFORT

There may be some discomfort and bruising when your blood is taken.

There is a small risk of injury during exercise: for example you may have muscle pain or strain due to the resistance or aerobic exercise.
There is a very small chance (less that one in one-hundred thousand) of having a heart attack while exercising, either during testing or during the training program. We do our best to minimize the chances of this happening by medical screening and supervision of exercise by qualified staff.

If an emergency occurs, tell your trainer or the Exercise Specialist immediately. If you are exercising on your own when an emergency occurs, let the YMCA or RA Centre staff know right away. The phone numbers of the HEARTY Study staff are in the HEARTY sign in binder at the front desk.

The magnetic field used by an MRI scan can cause certain types of metal to move, which could potentially cause injury. It is important to let the technologist know of any metal on or in your body or if you have ever had previous surgery. Some people feel claustrophobia (fear of closed spaces) during an MRI scan.

If you suffer an injury as a direct result of participating in this study, normal legal rules on compensation will apply. By signing this consent form you are not waiving your legal rights or releasing the Investigators from their legal professional responsibilities.

REIMBURSEMENT OF COSTS

You will be given a pass or money for your parking or bus transportation for each medical visit. Transportation to and from the gym is your responsibility.

BENEFITS

There is no promise that your participation in this study will improve your health. However, you will get a lot of support from the dietitian and exercise specialist throughout the study. If you do the exercise program and diet that is given to you, you will likely lose weight and improve your level of physical fitness.

At the end of the first 6-months you will be eligible to receive a $50 movie theatre gift certificate. You must complete the pedometer log at baseline, 3-month and 6-months **and** all of the following appointments at the 6-month point to receive your gift certificate: MRI scan, oral glucose tolerance test, strength test, dietitian appointment, VO2max and resting metabolic rate test.

STANDARD TREATMENT

Whether or not you participate in this study, you will receive your usual medical care just as you do currently.

CONFIDENTIALITY

We will make every effort to make sure that your name, personal information and the results of any tests are kept private at all times except as required or permitted by law. The data collected may be used in scientific publications, but your name will not be used. Any personal information about you that leaves the hospital will be coded so that you can not be identified by your name. Your relevant data will be available to the investigators, research staff and trainees working under the investigators' supervision, and the Ottawa Hospital Research Ethics Board for review purposes.

VOLUNTARY PARTICIPATION

You are free to choose not to participate in this study, or to take back your consent at any time. Your decision to participate or not in this study will not affect your medical treatment in any way. We will tell you about any new information that might change your mind about participating in the study.

The Investigators may stop your participation in the research study without regard to your consent, if there are any concerns regarding safety or risk.

A signed copy of the consent form, which describes the study, will be provided to you.

QUESTIONS

You have had and will continue to have opportunities to get information about this study from:

1) Dr. Janine Malcolm, Site Investigator at [redacted]
2) Dr. Ronald Sigal, Principal Investigator at [redacted]
3) Dr. Stasia Hadjiyannakis at [redacted]
4) Dr. Gary Goldfield at [redacted]
5) Penny Phillips, Research Coordinator at [redacted]

The Research Ethics Board protects the rights and well-being of people participating in research.

If you have any questions about your rights as a research participant, you may call the Chair of the Ottawa Hospital Research Ethics Board at [redacted] or the Chair of the CHEO Research Ethics Board at [redacted]

At the conclusion of the research study, you will be given a summary of your results.

CONSENT

I have read this 6-page Consent Form and Information Sheet.

I agree that I have been fully informed about the methods, treatments and tests for this study.

I have also been given a description of possible discomforts, risks and benefits. I understand that I will not be paid to participate in this study.

I know that my participation in this study is voluntary and that I am free to withdraw from it at any time.

Name of subject	Date
Signature of subject	
Name of parent/guardian (if required)	Date
Signature of parent/guardian (if required)	
Name of investigator's designee	Date
Signature of investigator's designee	

(Revised 23 OCT 08)
(Valid until 30 JAN 10)

Magnetic Resonance Imaging (MRI) Analysis

- ✓ MRI Body Composition Analysis Protocol & Analysis Procedures
- ✓ MRI Regional Body Composition Diagram

MRI Body Composition Protocol & Analysis Procedures

- Body composition was assessed by MRI using established protocols by Ross et al.:

  - Ross et al. Quantification of adipose tissue by MRI: relationship with anthropometric variables. J Applied Physiology 1992; 72: 787-95.
  - Ross et al. Influence of diet and exercise on skeletal muscle and VAT in men J Applied Physiology 1996; 81: 2445-2455.
  - Ross et al. Adipose tissue distribution measured by MRI in obese women. Am J Clin Nutr 1993; 57:470-5.

- The following description details the Ross et al. procedures involved in quantification of total and regional body composition analysis for the HEARTY study:

1. Analyst is trained in MRI analysis protocols and segmentation quantification in Dr. Robert Ross' laboratory, Queens University, Ontario, Canada.

2. Acquisition of MRI images by trained technicians at the Children's Hospital of Eastern Ontario or MRI plus at baseline and at post-intervention (6 months).

3. Cross-sectional MRI images are downloaded and opened using software Slice-o-matic v. 4.3 (Tomovision, QC) on two host computers at the University of Ottawa Human and Environmental Physiology Research Unit.

4. Analyst creates script files to organize the sequence of images so that Slice-o-matic reads them in the correct order from image 1 (toes) to 45 (fingers) following the established protocols by Ross et al.

5. Analyst performs image-by-image segmentation quantification (45 images total) using different colors (tags) representing different tissues with Slice-o-matic.

6. Once total body image segmentation is complete, Slice-o-matic generates a 'DB file' with the **AREA** (cm^2) of tissue in one image/slice using the formula:

   $$\text{AREA } (cm^2) = [(\sum \text{pixels}) \times \text{pixel surface area of that slice}]$$

7. Analyst calculates the **PARTIAL VOLUME** (cm^3) of tissue in each slice using the truncated cone model developed by Ross et al. (1992):

   $$\text{PARTIAL VOLUME } (cm^3) = \text{Area } (cm^2) \times \text{slice thickness } (1cm)$$

8. Analyst calculates the **TOTAL VOLUME** (Liters) of tissue using the formula:

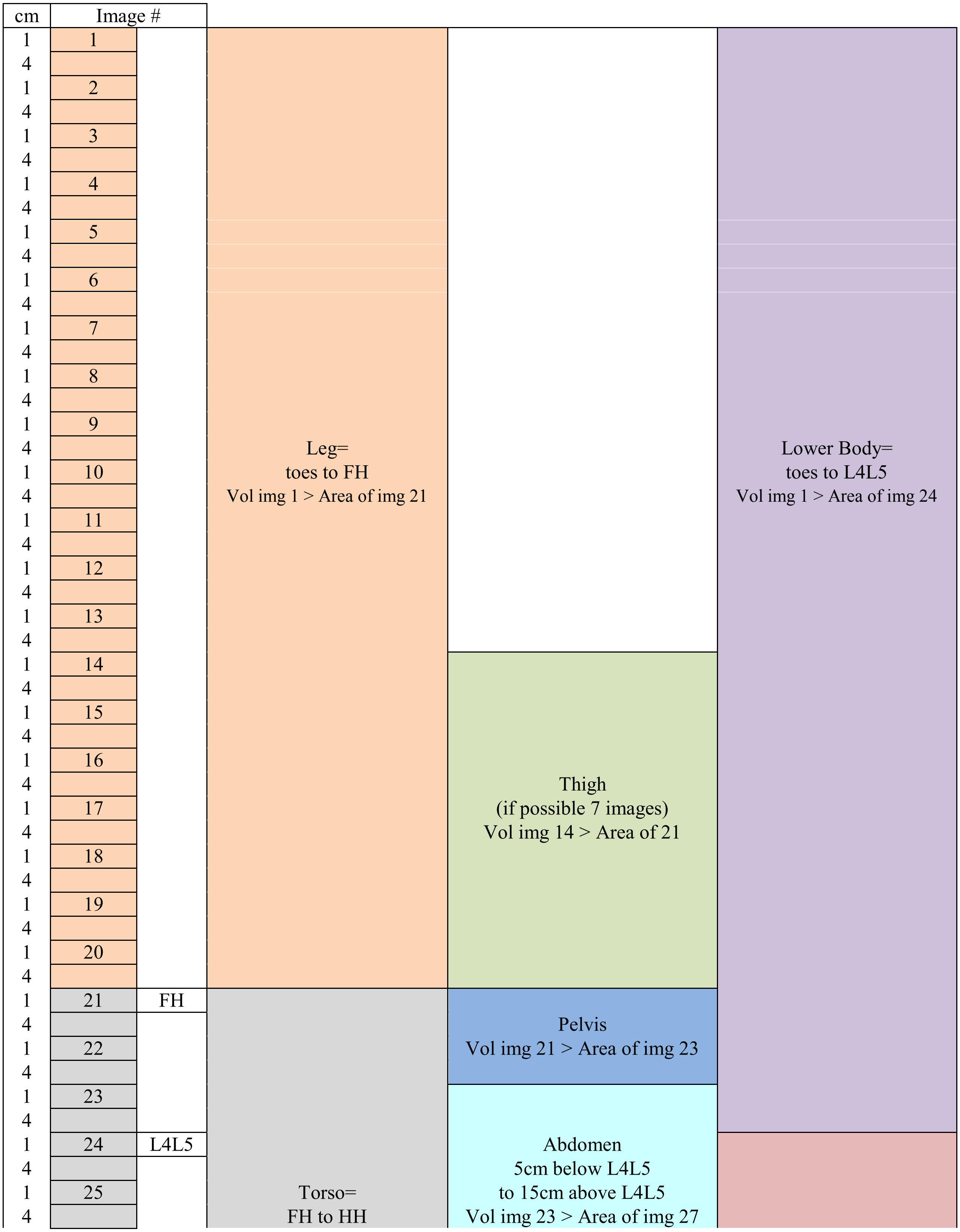
   TOTAL VOLUME (Liters) = ∑ truncated pyramids of consecutive partial volumes of all 45 slices

9. Analyst calculates the **TOTAL TISSUE MASS** (kilograms) = Liters x assumed constant densities for adipose tissue, skeletal muscle and lean tissue:

   - Adipose tissue mass (visceral, subcutaneous, intramuscular fat) = Adipose tissue volume (L) x 0.92 kg/L
   - Fat-free skeletal muscle mass= Skeletal muscle volume (L) x 1.04 kg/L
   - Lean tissue mass (organs, bone)= Lean tissue volume (L) x 1.08 kg/L

Reference for tissue densities: Snyder WS, Cooke MJ, Mnassett ES, Larhansen LT, Howells GP, Tipton IH. Report of the Task Group on Reference Man. Oxford: Pergamon; 1975.

MRI Regional Body Composition Diagram



Toes

cm	Image #				
1	1		Leg= toes to FH Vol img 1 > Area of img 21		Lower Body= toes to L4L5 Vol img 1 > Area of img 24
4					
1	2				
4					
1	3				
4					
1	4				
4					
1	5				
4					
1	6				
4					
1	7				
4					
1	8				
4					
1	9				
4					
1	10				
4					
1	11				
4					
1	12				
4					
1	13				
4					
1	14			Thigh (if possible 7 images) Vol img 14 > Area of 21	
4					
1	15				
4					
1	16				
4					
1	17				
4					
1	18				
4					
1	19				
4					
1	20				
4					
1	21	FH	Torso= FH to HH	Pelvis Vol img 21 > Area of img 23	
4					
1	22				
4					
1	23			Abdomen 5cm below L4L5 to 15cm above L4L5 Vol img 23 > Area of img 27	
4					
1	24	L4L5			
4					
1	25				
4					

1	26		Vol Img 21 > Area of img 32		Upper Body= L4L5 to fingers Vol img 24 > Area of img 45
4					
1	27			Thorax Vol of img 27 > Area of img 32	
4					
1	28				
4					
1	29				
4					
1	30				
4					
1	31				
4					
1	32	HH	Arm= HH to fingers Vol HH > Area of img 45		
4					
1	33				
4					
1	34				
4					
1	35				
4					
1	36				
4					
1	37				
4					
1	38				
4					
1	39				
4					
1	40				
4					
1	41				
4					
1	42				
4					
1	43				
4					
1	44				
4					
1	45				

Fingers

Abbreviations: cm= centimeter (represents image thickness or the distance between consecutive images), FH= Femoral Head landmark, HH= Humeral Head landmark, img= image, L4L5= cross-sectional image between 4th & 5th lumbar vertebra.

Data Collection Sheets

- ✓ Cardiorespiratory Fitness Test
- ✓ Musculoskeletal Fitness Tests

Cardiorespiratory Fitness Test: Modified Balke & Ware treadmill VO_{2peak} testing protocol

Patient's Name: ____
Date: ____
Visit: ________M
Protocol: slow tmt regular tmt fast tmt (circle one)

	Grade	Speed	BP
	(%)	(mph)	(mmHg)
rest	0	0	____/____
0:00	0		-
1:00	0		-
1:30	0		-
2:00	0		-
2:30	0		-
3:00	1.5		-
3:30	1.5		____/____
4:00	3		-
4:30	3		-
5:00	4.5		-
5:30	4.5		____/____
6:00	6		-
6:30	6		-
7:00	7.5		-
7:30	7.5		____/____
8:00	9		-
8:30	9		-
9:00	10.5		-
9:30	10.5		____/____
10:00	12		-
10:30	12		-
11:00	13.5		-
11:30	13.5		____/____
12:00	15		-
12:30	15		-
13:00	16.5		-
13:30	16.5		____/____
14:00			-
14:30			-
15:00			

Time Recovery started: ______________

	BP
Recovery	(mmHg)
0:30	____/____
2:00	____/____
3:00	____/____

Terminated b/c: ___________________

Musculoskeletal Fitness Tests: 8-RM & Canadian Physical Activity, Fitness & Lifestyle Appraisal tests (part 1 of 2)

	Trial 1	Trial 2
Grip Strength R		
Grip Strength L		

CENTRE:	
Chest Press (8RM)	

	Number Completed
Push up (M / F)	

CENTRE:	
Leg Press (8RM)	

	Trial 1	Trial 2
Sit and Reach		

CENTRE:	
Bench Press (8RM)	

	Number Completed
Partial Curl-Up	

Distance reached if none completed: ____________ cm

	Trial 1	Trial 2	Trial 3
Stand and Reach			
Vertical Jump			
Jump Height (difference)			

Musculoskeletal Fitness Tests: 8-RM & Canadian Physical Activity, Fitness & Lifestyle Appraisal tests (part 2 of 2)

Healthy Musculoskeletal Fitness – Composite Scoring

Name: ____________________

Date: _______________

Visit: ______

Age: _____

Appraisal Items	Measurement	Rating (NI, Fair, etc.)	Weighted Score	Maximum Attainable Weighted Scores	
				Male	Female
Grip Strength (kg)					
Push-up					
Sit and Reach (cm)					
Partial Curl-ups					
Let Power (watts)					

Total Maximum Attainable Weighted Score: /28 /28
Total Weighted Score Achieved: ______

Composite Musculoskeletal Fitness Score: ______ (out of 4)

Composite Musculoskeletal Rating:
NI F G VG E

*Leg Power (W) = [60.7 x jump height (cm)] + [45.3 x body mass (kg)] – 2055

Knowledge Translation Invitation
Invitation from the Canadian Society for Exercise Physiology (CSEP):

Invitation from CSEP

From: **Jakobi, Jennifer** [redacted]
Sent: June-12-13 8:30:42 AM
To: [redacted]

Dear Dr. Alberga

I am writing on behalf of the Knowledge TransferCommittee for the Canadian Society for Exercise Physiology (CSEP).We have identified your article: *Top 10 practical lessons learned from physical activity interventions in overweight and obese children and adolescents* published in Applied Physiology and Nutrition (38(3): 249-258, 10.1139/apnm-2012-0227) as a topic that is pertinent and of interestto the CSEP community.

The CSEP is the principal body for physical activity, health and fitness research and personal training in Canada. We foster the generation, growth, synthesis, transfer and application of the highest quality research, education and training related to exercise physiology and science. We are the GOLD STANDARD of health and fitness professionals dedicated to getting Canadians active safely by providing the highest quality customized and specialized physical activity and fitness programs, guidance and advice based on extensive training and evidence-based research. One means of disseminating information relative to this mission, is research summaries that are published through our monthly Communiqué.

Congratulations to you and your co-authors on an informative article. We believe your article incorporated information that is of meaningful translation to the broader CSEP community. In acknowledging this, I am inviting you to write a short summary of the article for dissemination in the CSEP Communique, our organization's monthly on-line newsletter. This article should be approximately 300-500 words, and should be written as a lay language summary for easy comprehension by the '*non expert*'in the field. Your summary should identify the applicability of your research to the applied Health and Exercise members. These members work directly in the community to promote, teach and enhance the health and well-being of Canadians through exercise and nutrition modification.

The CSEP Knowledge Translation Committee has identified thisCommuniqué as a means of increasing the visibility and practical utility of research and through this resource we endeavor to enhance knowledge of our practitioners and Canadians. I am hopeful that you will agree to this request. A brief set of instructions for authors, and the citation method are listed below. Please respond to me by email to indicate your willingness to write this summary brief translational piece.

Jennifer (Jenn) Jakobi

Canadian Soceity for Exercise Physiology (CSEP)

Chair, Knowledge Translation Committee

Contact: IGS Director

College of Graduate studies

UBC Okanagan

****

Instructions to the authors:

This is to be a summary of the original article, written in a manner to make it comprehensible for professionals in the fitness industry. References are not needed, but if the author would like to include references, they should be done in the format of APNM. The summary should be approximately 300-500 words in length. Documents should be prepared using a standard word processing program.

For examples please see:http://www.csep.ca/english/view.asp?x=724

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Top 10 practical lessons learned from physical activity interventions in overweight and obese children and adolescents

Angela S. Alberga, Emily R. Medd, Kristi B. Adamo, Gary S. Goldfield, Denis Prud'homme, Glen P. Kenny, and Ronald J. Sigal. *Appl. Physiol. Nutr. Metab.* 38: 249–258, 2013.

Physical inactivity and obesity in children and youth are great public health concerns. Despite the well-known benefits of exercise that go above and beyond solely weight loss, participation rates are relatively low, and many who initiate exercise programs do not continue long-term. The difficulty lies in designing and implementing exercise programs for children and adolescents that are enjoyable, feasible and sustainable in the long run. Despite exercise being a focal point for obesity management in children and adolescents, practical advice on improving adherence to physical activity for overall health is lacking and warrants attention from the community at large.

The purpose of this paper was to propose practical advice on best practices related to physical activity interventions in overweight and obese children and adolescents. The practical recommendations stem from our collective clinical trial research experiences and are further supported by other published research studies in this population.

The top 10 lessons learned are (1) Physical activity setting–context is important. It should take the participant's social and cultural values into account and should be at an accessible location with a respectful and welcoming environment. (2) Choice of fitness trainer matters. They should be skilled and knowledgeable in kinesiology and health behavior change as well as understand the physiological and psychosocial complexity of pediatric obesity. (3) Physical activities should be varied and fun and should reflect the participant's preferences to increase motivation and adherence to physical activity. (4) The role of the parent–guardian should be considered. (5) The participant's physical and psychosocial characteristics should be accounted for, highlighting the importance of catering the exercise program to the individual. (6) Realistic goals should be set and (7) regular reminders should be offered according to the participant's preferred method of communication. (8) A multidisciplinary approach should be taken to provide continuous support and program adjustment from diverse health professionals to help deter from dropout. (9) Any social, familial, biological, behavioral, and environmental barriers to physical activity participation should be identified early by questionnaire or interview and a plan to overcome them developed. Lastly, (10) the right message should be communicated to participants: specifically, what's in it for them? Family-centered care is of utmost importance so that realistic outcomes are explained simply and effectively to participants. Exercise should be promoted as a gateway for improving *overall health* rather than focusing on weight loss alone in youth with obesity.

The recommendations in this paper can be used at the individual, community, provincial and federal level with the hope of increasing adherence and increasing the health benefits of physical activity participation in youth. This paper serves as a practical guide for parents, community members, educators, exercise specialists, exercise facility managers, clinicians, future investigators and policy makers. The practical application of this paper has the potential to help health professionals better cater exercise programs to youth and to influence public policy to help maintain the health and physical activity of children throughout the lifespan.

Reference

Angela S. Alberga, Emily R. Medd, Kristi B. Adamo, Gary S. Goldfield, Denis Prud'homme, Glen P. Kenny, and Ronald J. Sigal. **Top 10 practical lessons learned from physical activity interventions in overweight and obese children and adolescents.** Appl. Physiol. Nutr. Metab. 38: 249–258, 2013.

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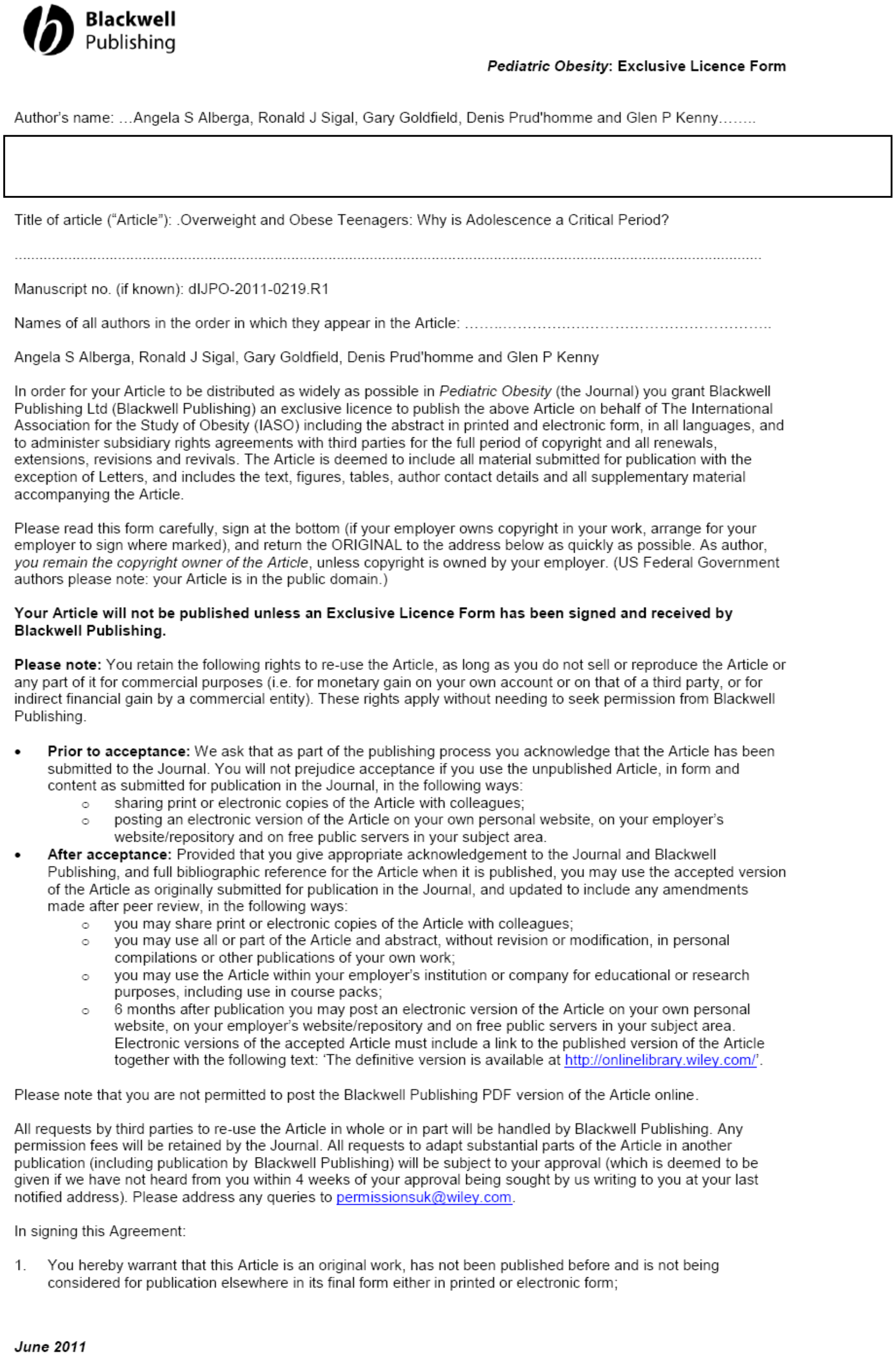

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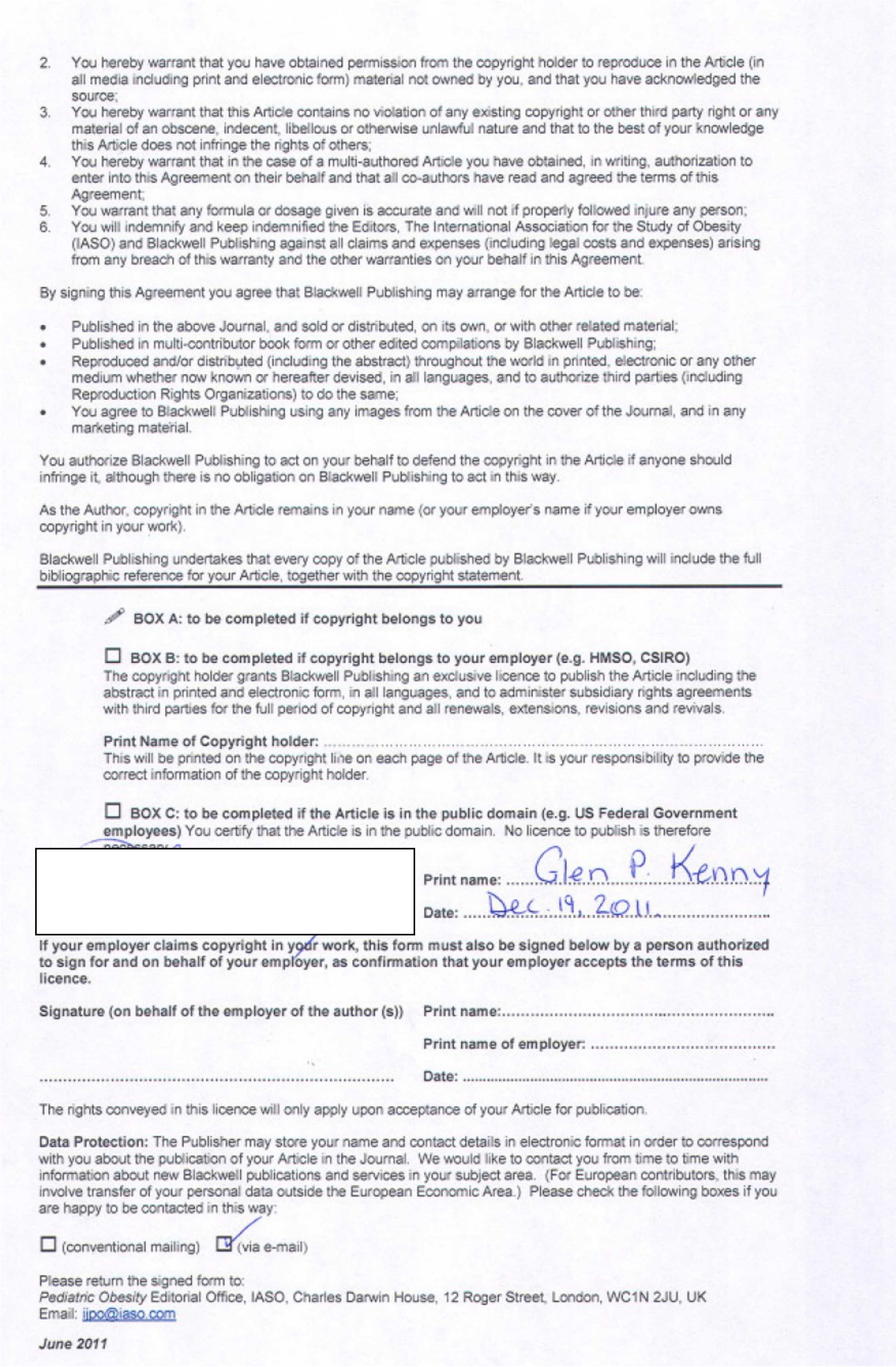

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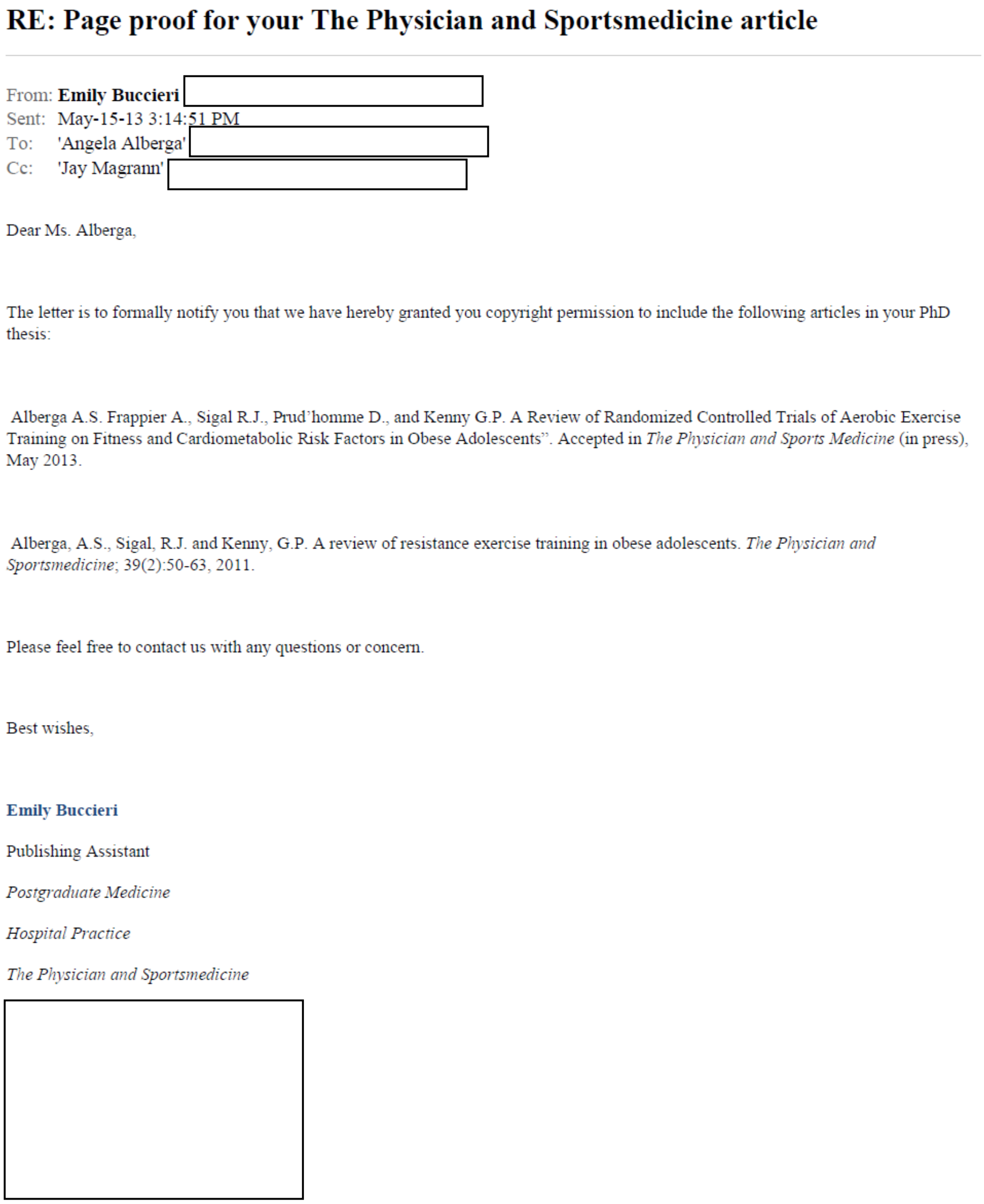

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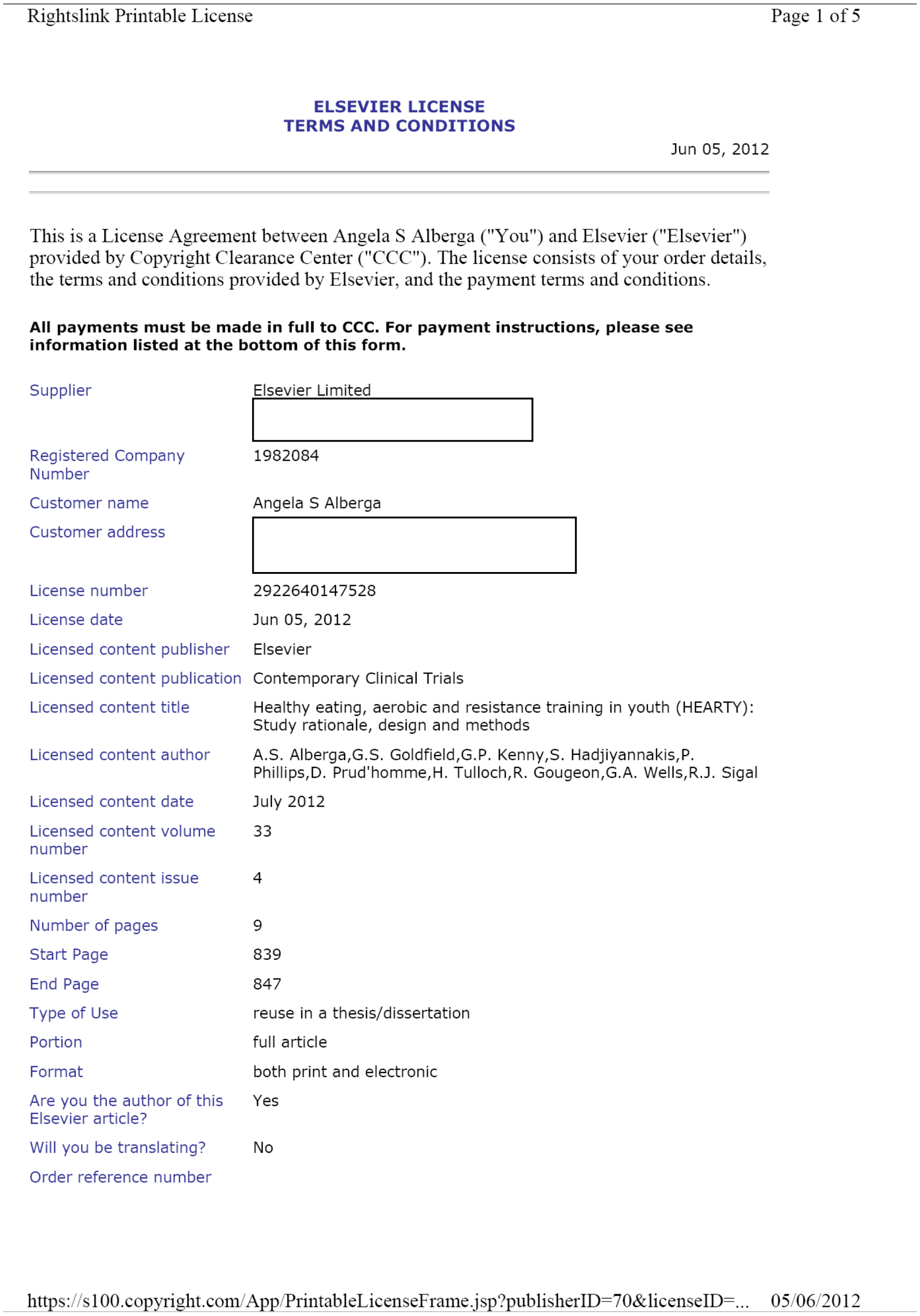

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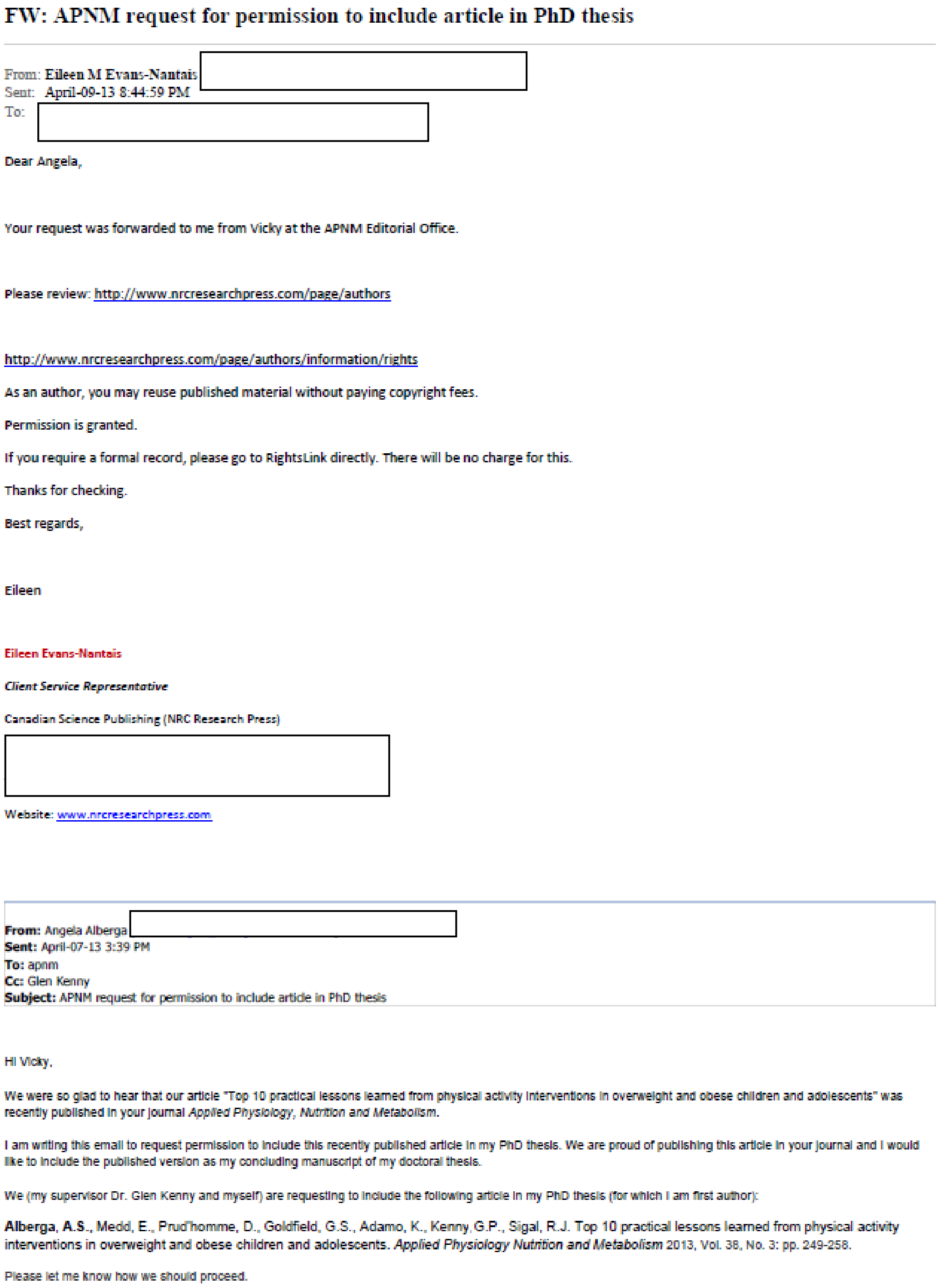

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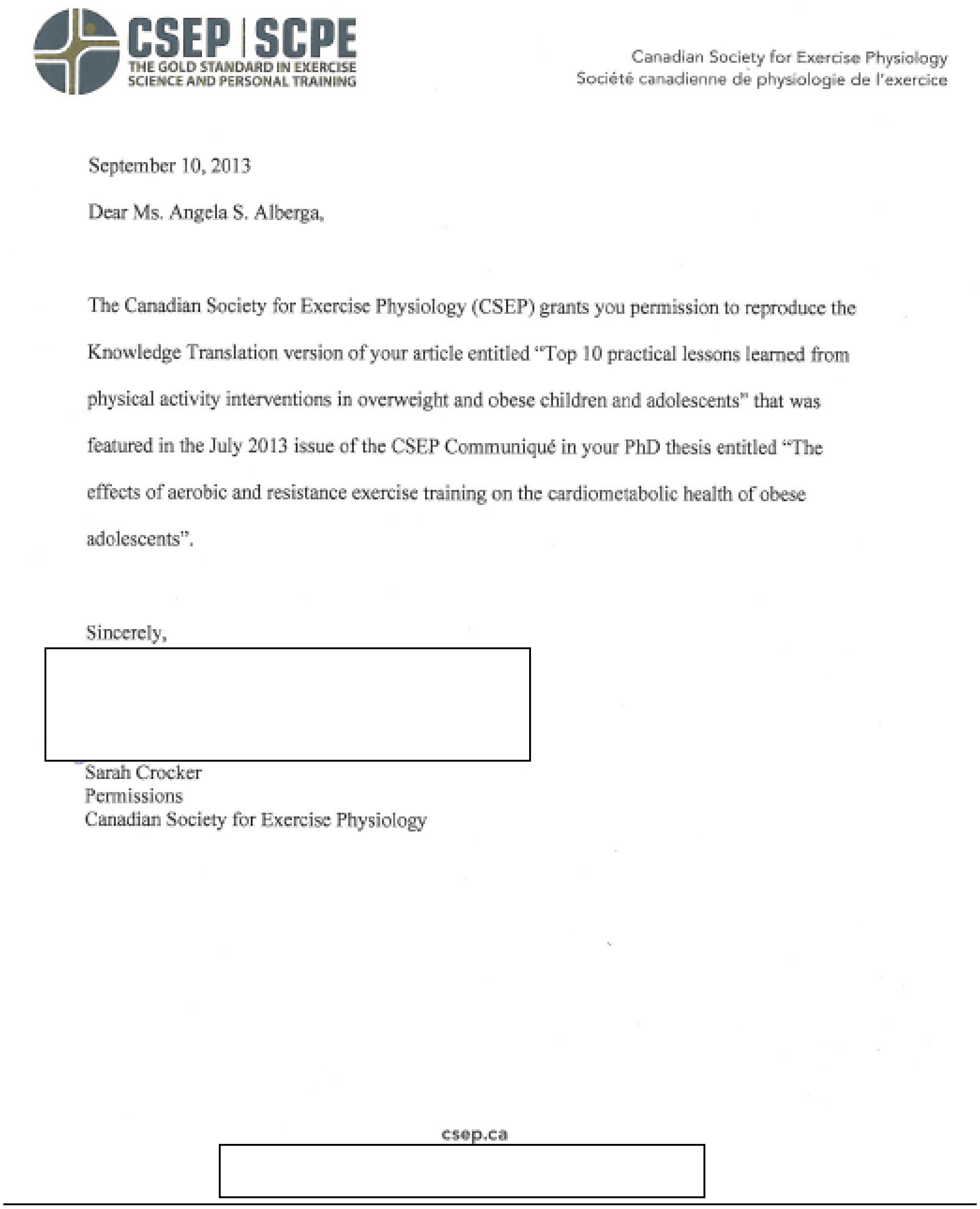

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September 10, 2013

Dear Ms. Angela S. Alberga,

The Canadian Society for Exercise Physiology (CSEP) grants you permission to reproduce the Knowledge Translation version of your article entitled "Top 10 practical lessons learned from physical activity interventions in overweight and obese children and adolescents" that was featured in the July 2013 issue of the CSEP Communiqué in your PhD thesis entitled "The effects of aerobic and resistance exercise training on the cardiometabolic health of obese adolescents".

Sincerely,

[redacted]

Sarah Crocker
Permissions
Canadian Society for Exercise Physiology

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[redacted]