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**Efficacy of Exercise Intervention for Weight Loss in Overweight and Obese Adolescents: Meta-Analysis and Implications**

Running Title: Exercise and Weight Loss in Overweight and Obese Adolescents

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# Abstract

*Background*: The global rise in obesity prevalence among children and adolescents has been linked to modifiable lifestyle factors, including lack of physical activity. However, no known meta-analysis has been conducted on the effects of exercise intervention on body composition and metabolic risk factors in overweight and obese adolescents.

*Objectives*: (i) To estimate whether exercise intervention meaningfully improves body composition and cardio-metabolic risk factors in overweight and obese adolescents. (ii) To discuss the implications of the findings in terms of primary healthcare provision and public health policy, using New Zealand as an exemplar context.

*Data Sources*: Electronic databases (PubMed, Web of Science SPORTDiscus, Google Scholar) from inception to May 2015. The reference lists of eligible articles and relevant reviews were also checked.

*Study Selection*: Inclusion criteria: (i) randomized controlled trial; (ii) structured exercise intervention, alone or combined with any other kind of intervention; (iii) control group received no structured exercise or behavioural modification designed to increase physical activity; (iv) participants overweight or obese (body mass index >85th percentile); (v) participants aged between 10 and 19 years.

*Appraisal and Synthesis Methods*: Initially, 1667 articles were identified. After evaluation of study characteristics, quality and validity, data from 13 articles (15 trials) involving 556 participants (176 male; 193 female; 187 unknown) were extracted for meta-analysis. Meta-analyses were completed on 5 body composition parameters and 10 cardio-metabolic parameters. Effect sizes were calculated as mean differences, as well as standardized mean differences in order to determine effect magnitude.

*Results*: Exercise intervention reduced body mass index (mean: 2.0 kg/m2, 95% CI 1.5, 2.5; effect size (ES): moderate), body weight (mean: 3.7 kg, 95% CI 1.7, 5.8; effect size: small), body fat percentage (3.1 %, 95% CI 2.2, 4.1; effect size: small), waist circumference (3.0 cm, 95% CI 1.3, 4.8; ES: small), but the increase (improvement) in lean mass was trivial (mean: 1.6 kg, 95% CI 0.5, 2.6). The response to an oral glucose tolerance test following exercise intervention was for a decrease in the area under the curve for insulin (mean: 162 μU/ul, 95% CI 93, 231; ES: large) and blood glucose (mean: 39 mg/dl, 95% CI 9.4, 69; ES: moderate). There were also improvements in the homeostatic model assessment (mean: 1.0, 95% CI 0.7, 1.4; ES: moderate) and systolic blood pressure (mean: 7.1 mm Hg, 95% CI 3.5, 10.7; ES: moderate). The effects of exercise on total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, fasting insulin and fasting blood glucose were inconclusive.

*Limitations*: Most included trials were short term (6 - 36 weeks) and 13 had methodological limitations. Additionally, the meta-analyses for some of the secondary outcomes had a small number of participants or substantial statistical heterogeneity.

*Conclusions*: The current evidence suggests that exercise intervention in overweight and obese adolescents improves body composition, particularly by lowering body fat. The limited available evidence further indicates that exercise intervention may improve some cardio-metabolic risk factors.

# Key Points

* Exercise intervention in overweight and obese adolescents results in worthwhile improvements in body composition, particularly body fat.
* More limited evidence indicates that exercise intervention substantially improves some cardio-metabolic risk factors.
* The efficacy of exercise interventions should be determined using sensitive markers of body composition as well as cardio-metabolic risk.

# 1 Introduction

A recent opinion piece entitled “It is time to bust the myth of physical inactivity and obesity: you cannot outrun a bad diet”, claimed that exercise does not work for weight loss.[1] The resulting controversy,[2, 3] which resulted in the article’s temporary retraction, highlights some of the polarised assumptions around the growing burden of childhood and adolescent obesity.[4, 5] According to the opinion piece,[1] the weight of evidence suggests that obesity prevention should target nutrition and not exercise. However, this argument is founded on two major assumptions: (i) that obesity is currently classified appropriately; and (ii) obesity is the most important component of health and development. First, obesity is typically classified using body mass index (BMI). Previous research has shown there is an imperfect association between BMI and body fatness,[6] particularly when lean tissue mass is altered, i.e., such as may occur with certain forms of exercise. Second, obesity is not the key health determinant, but rather it is a risk factor for non-communicable diseases (NCDs).

It is well understood that obese children and adolescents are at increased risk of premature onset of NCDs, including musculoskeletal disorders, some cancers, and particularly cardio-metabolic diseases.[7] The premature and prolonged burden of NCDs carries significant economic consequences.[8-10] For example, in New Zealand, which currently ranks as the fourth-worst OECD country for obesity prevalence,[4] the estimated health care costs of overweight and obesity were NZ$624m in 2006, or 4.4% of the total health care expenditure.[10] These figures, which are likely to continue to outpace the growth of New Zealand’s gross domestic product, are purely economic and do not reflect the social costs of obesity to individuals and communities.[9]

Being physically active may mitigate the risk of developing NCDs by regulating energy balance and preventing obesity. However, just as importantly, adequate physical activity is required for the optimal physical and psychological development of children.[11, 12] Aside from increasing lean tissue mass, physical activity raises metabolic rate, increases bone density, helps cardiac muscle become stronger, and increases the elasticity of the arterial system.[11, 12] In sum, exercise results in a number of physiological adaptations, beyond regulating body weight, that may be important for ensuring cardio-metabolic health and preventing the onset of NCDs.

To our knowledge, no meta-analysis has been conducted on the effects of exercise intervention on body composition and metabolic risk factors in overweight and obese adolescents. The current analysis aimed to identify and quantitatively review randomized controlled trials assessing the effects of exercise intervention, with or without nutrition or behavioural co-intervention, on anthropometric, body composition and cardio-metabolic risk factors. Finally, the implications of the findings are discussed in terms of primary healthcare provision and public health policy in New Zealand, a relatively small Westernized country which may serve as a microcosm for other developed nations.

# 2 Methods

This meta-analysis was carried out in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[13]

## 2.1 Data Sources and Searches

Electronic databases (PubMed, Web of Science, SPORTDiscus, Google Scholar) were searched by two authors (LS, AM) utilising the keywords: (adolescent) AND (physical activity OR exercise) AND (obesity OR

overweight OR BMI OR body mass index OR body weight OR fat mass). The reference lists of all identified trials and relevant reviews or editorials were also examined. The search was limited to English language articles published between inception and May 2015.

## 2.2 Article Selection

For the purpose of this meta-analysis the term ‘article’ is used synonymously with ‘study’, and ‘trial’ is the unit included in the meta-analysis. A given article may have resulted in more than one eligible ‘trial’ if the article included more than one intervention group. Initially, article titles and abstracts were screened for relevance. The full-text of potentially eligible articles were obtained to review eligibility for inclusion. The following criteria were used to select trials for inclusion in the review: (i) the trial was a randomized controlled trial; (ii) use of a structured exercise intervention, alone or combined with other lifestyle interventions; (iii) the control group received no structured exercise or behavioural modification designed to increase physical activity; (iv) the participants were overweight or obese (BMI >85th percentile[14]); (v) the participants were aged between 10 and 19 years. Selection criteria were not limited by study duration, exercise intensity, or exercise modality. In trials with multiple treatment arms and a single control group, the sample size of the control group was divided by the number of treatment groups to avoid over-inflation of the sample size [15]. Repeated publications for the same trial were excluded. Three researchers (LS, AM, DC) completed the study selection independently.

## 2.3 Data Extraction and Quality Assessment

Data extracted for each eligible trial included bibliographic information (author, publication year), baseline participant characteristics, details of intervention(s), and results of reported outcomes. Study quality was assessed using the modified Jadad’s score (range 0–5), which includes items related to randomization, blinding and description of dropout/withdrawals.[16] Because it is difficult (if not impossible) to blind participants to an exercise intervention, we considered the blinding of the operator to the outcome assessment as a quality criterion. Data extraction, quality assessment, and scrutiny of the exercise interventions were completed by an exercise physiologist (LS) and a clinical exercise physiologist (KG).

## 2.4 Data Synthesis

For each outcome of interest, the pre- and post-intervention values (mean and standard deviation), as well as mean differences and associated standard deviations, were entered in to a spreadsheet. When mean differences and associated standard deviations were not published, they were estimated from the pre- and post-intervention values based on methods from the Cochrane Handbook for Systematic Reviews of Interventions.[15] For articles reporting multiple time points, only the final time point was used in analyses. Primary outcomes were anthropometric (BMI, body weight, waist circumference) and body composition (adipose and lean tissue) variables. Cardio-metabolic outcomes were systolic blood pressure, total cholesterol, low-density lipoprotein cholesterol (LDL), high-density lipoprotein cholesterol (HDL), triglycerides, fasting glucose, fasting insulin, the homeostatic model assessment (HOMA), and area under the curve (AUC) for glucose and insulin following an oral glucose tolerance test (OGTT). Aggregation and calculation of final results was conducted by one author (LS).

## 2.5 Data Analysis

All extracted data were entered into software designed specifically for meta-analyses (Open Meta-Analyst, <http://www.cebm.brown.edu/open_meta>). A fixed-effect model was used for the meta- analyses as we hypothesized that the exercise interventions were estimating one underlying effect. The software calculated the effect size as the mean difference, as well as the standardized mean difference (SMD). The SMD was used to determine the magnitude of the effect, where <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large.[17, 18] We chose a SMD of 0.2 as the smallest worthwhile change for all clinically-associated mechanistic parameters. Inference relative to the likelihood of change relative to the smallest worthwhile effect size was drawn from the method of Hopkins et al, [19, 20], where, an effect was unclear (inconclusive) if its confidence interval included both substantial positive and negative values (i.e., >5% probability that the true value is greater than both SMD +0.2 and -0.2). Otherwise, the likelihood of a worthwhile effect was calculated from the two-tailed t-distribution summarized as follows: 0.5%, almost certainly not; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most certain. The statistical heterogeneity across different trials in meta-analysis was assessed by the I2 statistic [21], where <25% indicates low risk of heterogeneity, 25-75% indicates moderate risk of heterogeneity, and >75% indicates considerable risk of heterogeneity [21, 22]. Publication bias was evaluated by visual inspection of the Begg’s funnel plot Egger’s test for asymmetry when (i) at least 10 trials were included in the meta-analysis, and (ii) there was substantial variation in sample size for the included trials [15]. Sensitivity analyses were carried out by excluding one trial at a time to test the robustness of the pooled results. Two authors (LS, DR) conducted the data analysis.

# 3 Results

## 3.1 Literature Search and Article Selection

A total of 1667 potentially eligible articles were identified. Following screening of abstracts and titles 1641 were excluded because they did not meet selection criteria. Of these, 15 randomized control trials, from 13 articles,[23-35] were identified for inclusion (Figure 1). Four trials [36-39] were excluded because the intervention group received a behavioural intervention, i.e., not structured exercise. Four trials were excluded because the control group received behavioural modification,[40-43] and 1 trial because the control group received dietary restriction.[44] One trial was excluded because post-intervention data was not reported,[45] and 1 trial because the participants were not overweight.[46]

## 3.2 Description of the Included Trials

### 3.2.1 Trial Setting and Participants

Included trial characteristics are summarized in Table 1. The trials were carried out in the US (n = 6), [23-25, 29, 31] China (n= 2),[32] Korea (n= 2),[27, 28] Singapore (n= 1),[35] Australia (n= 1),[34] Iran (n= 1),[33] Germany (n= 1),[30] and Tunisia (n= 1).[26] The exercise programme setting included schools (n= 8),[26-29, 32, 33] research laboratories (n= 3),[23, 24] hospitals (n= 3),[25, 31, 34] or not reported.[30] The number of participants in each trial ranged from 15 to 152. Three trials included only female participants [23, 24, 28] and two trials only male participants.[27, 35] The mean age of the participants ranged from 12.2 years (range: 10 – 16 y) to 17.0 years (SD: 0.6). Only three trials reported ethnicity, two of which recruited Latino adolescents,[23, 24] and one reported mixed ethnicity.[29]

### 3.2.2 Interventions

A brief description of the exercise interventions is given in Table 1. The duration of interventions varied in length from 8 weeks to 36 weeks, with a median of 12 weeks. The trials included aerobic exercise only (n= 5),[27, 28, 30, 32, 34] aerobic plus strength training (n= 1),[35] aerobic exercise plus nutrition/behaviour co-intervention (n= 6),[25, 26, 29, 31-33] strength training plus nutrition co-intervention (n= 2),[23, 24] and aerobic plus strength training and nutrition/behaviour co-intervention (n= 1).[24] The control groups consisted of usual care or untreated waiting list (n= 10),[23-28, 30, 31, 35] Tai Chi (n= 1),[34] Red Cross safety programme (n= 1),[29] or not reported (n= 3).[32, 33] The exercises were supervised for the majority (n= 12) of the trials,[23-30, 34, 35] with the remainder (n= 3) not reported.[31-33]

## 3.3 Methodological Quality Assessment

The methodological assessment of included trials is summarized in Table 1. The quality of the included trials ranged from 1–5, with a median quality score of 1. Although all of the trials were randomized, only five stated that the allocation process was concealed.[23-25, 34] Two trials stated that the outcome assessors were blinded,[25, 34] 5 trials adequately described withdrawal rates and reason for withdrawal.[23, 24, 29, 34] Only 6 trials [26, 28, 31-33, 35] reported a fitness assessment as a measure of intervention effectiveness, none of which conducted a full maximal oxygen uptake test. Three trials assessed fitness using a submaximal cycle test,[26, 31, 35] 1 trial a maximal cycle test,[30] 2 trials a 800 m (girls) or 1000m (boys) timed run test,[32] and 1 trial did not report the assessment method.[28]

## 3.4 Synthesis of the Results

The effects of exercise intervention, alone or combined with other lifestyle interventions, on the 15 selected outcomes are summarized in Table 2 and reported below. Numerical values are presented as the mean difference (95 % confidence interval, CI) unless otherwise reported.

### 3.4.1 Fitness

The 7 trials reporting a fitness assessment used varying methodologies, therefore only the standardized mean difference (SMD) is reported. The meta-analysis indicated a most certain large improvement, but the heterogeneity was high and this finding needs to be interpreted with caution.

### 3.4.2 Effects on Body Composition

Following exercise intervention there was a most certain moderate reduction in BMI, and most certain small reductions in body weight and fat percentage, and waist circumference. There was a most certain trivial increase (improvement) in lean tissue mass. Sensitivity analysis was conducted on each outcome except waist circumference. One trial [26] influenced the BMI and body weight outcomes; its removal decreased the mean difference to 1.5 kg/m2 (95% CI: 1.5, 2.5) and 2.8 kg (95% CI: 0.6, 5.0) respectively. Further, one trial [25] influenced the body fat percentage and lean tissue mass outcomes; its removal decreased the mean difference to 2.1 % (95% CI: 1.0, 3.2) and 0.2 kg (95% CI: -1.0, 1.4), respectively. Inspection of the funnel plots indicated no evidence of publication bias.

### 3.4.3 Effects on Cardio-Metabolic Outcomes

There was a most certain large improvement in the insulin AUC (OGTT) and very likely moderate improvement in the glucose AUC (OGTT). There were also most certain moderate improvements in HOMA and systolic blood pressure; however, the heterogeneity was high and these findings should be interpreted with caution. There was a likely trivial improvement in LDL cholesterol, but unclear changes in fasting glucose, fasting insulin, total cholesterol and HDL cholesterol.

## 3.5 Subgroup Analyses

For the anthropometric and body composition outcomes with a sufficient number of trials (i.e., BMI, body fat, lean tissue mass), subgroup analyses were carried out to examine whether nutrition co-intervention affects the estimates of effect size. The three articles with a nutrition-only arm were also included in this analysis. For the co-intervention subgroup there were most certain moderate improvements in BMI and body fat, and most certain small improvements in body weight and lean tissue mass. For the exercise-only subgroup there was a very likely small-moderate improvement in BMI, and unclear changes in body weight, body fat percentage, and lean mass. For the nutrition-only subgroup there were unclear changes in all parameters.

# 4 Discussion

To our knowledge, this is the first meta-analysis examining the effects of exercise intervention on change in body composition and cardio-metabolic markers in overweight-obese adolescents. Based on the small number of randomized control trials available, we found that exercise intervention led to a moderate decrease in BMI, a small-moderate decrease in waist circumference and body fat, and a trivial increase (improvement) in lean tissue mass. Review of available evidence suggests that exercise led to a moderate decrease in systolic blood pressure, and moderate-large improvements in glucose handling, commensurate with improved insulin sensitivity. Sub-group analysis revealed that while exercise-only intervention led to a small-moderate improvement in BMI, exercise plus nutrition co-intervention resulted in moderate improvements in BMI and body fat, and a trivial improvement in lean tissue mass. The meta-analysis on nutrition-alone intervention revealed inconclusive effects of this treatment.

## 4.1 Body Composition

Our analyses revealed that exercise intervention, alone or combined with other lifestyle interventions, resulted in a mean 3.7 kg decrease in body weight. While the findings must be interpreted with caution, owing to differences across trials in methodology used to measure body composition, we also found that lean tissue mass increased by mean of 1.6 kg and body fat decreased by a mean of 3.1%. These findings reiterate previous evidence indicating that BMI may be an insensitive indicator of body composition in both adults [47] and adolescents.[48]

The calculation of BMI assumes that the ratio between height and weight provides an index of body fatness. However, (i) there is an imperfect association between BMI and body fatness, particularly when lean tissue mass is altered, and (ii) BMI does not distinguish adipose distribution.[6, 49] The use of BMI may be especially inappropriate for interventions including a strength training component,[47] as was the case for 4 of the trials included in the current meta-analysis, [23, 24, 35] 1 of which reported an increase (worse) in BMI[24] and 2 reported no change.[23, 35] Given the small number of trials, we did not perform subgroup analysis on the trials with and without a strength training component; this is a limitation of the current analysis and further research is required to clarify the additive effects of aerobic plus strength training in overweight-obese adolescents.

## 4.2 Cardio-Metabolic

According to the World Health Organization (WHO), hypertension is likely the leading risk factor for death worldwide.[50] Therefore, while some caution must be applied owing to the small number of trials, our finding of a mean 7.1 mmHg decrease in systolic blood pressure following exercise intervention is meaningful. The systolic blood pressure for the adolescents assigned to the exercise group in the current meta-analysis was 126 mmHg, which would classify them as pre-hypertensive.[51] For an adult with a systolic blood pressure of 130 mmHg, a meta-analysis of 147 randomized trials reported that one standard dose of a blood pressure lowering drug decreased systolic blood pressure by a mean of 6.7 mmHg.[52] While similar data are unavailable for adolescents, the current meta-analysis supports previous work demonstrating the importance of exercise to cardiovascular health in overweight-obese children.[53]

In addition to improving systolic blood pressure, the current meta-analysis found moderate-large improvements in the capacity to regulate glucose and insulin during an OGTT (39% and 44% improvement, respectively), and a 1.02 unit improvement in HOMA. These findings are comparable to those reported in a recent meta-analysis of type 2 diabetic adults, where resistance- and aerobic-exercise improved HOMA by a mean of 0.73 (95% CI: 0.26-1.72) and 0.80 (95% CI: 0.50-2.11) units, respectively.[54] Moreover, these findings are comparable to a meta-analysis which reported that metformin – a popular anti-diabetic medication – improved HOMA by a mean of 1.06 (95% CI: 0.39, 1.72) units in obese children and adolescents.[55] Collectively, these findings suggest that exercise therapy may be as effective as drugs for regulating glucose metabolism.

The current meta-analysis indicated unclear changes in triglycerides, total cholesterol and HDL cholesterol, and a likely improvement in LDL cholesterol. This observation is inconsistent with a previous systematic review reporting improvements in HDL cholesterol and triglycerides following aerobic exercise in youth.[56] Possible explanations for this discrepancy included: (i) the mean duration of exercise intervention (14 weeks) for trials included in the current meta-analysis was insufficient to completely reverse overweight-obesity; (ii) the modality of prescribed exercise intervention. For the current meta-analysis the mean BMI decreased from 31 kg/m2 (obese) to 29 kg/m2 (overweight), and body fat percentage from 39 % to 36 %, meaning the adolescents still carried excessive fat mass. Fat cells secrete free fatty acids, which may stimulate hepatic triglyceride and very low density lipoprotein cholesterol production in both adults and youth.[57] To decrease fat mass to healthy levels, and limit the secretion of free fatty acids, longer duration exercise intervention may be required. In terms of exercise modality, the systematic review [56] reported that aerobic exercise was more beneficial than strength training for regulating blood lipids. The current meta-analysis included only 6 trials,[27, 28, 30, 32, 35] which were a mixture of aerobic, strength and nutrition interventions, making only generalizations possible. Further, the quality of these 6 trials was poor (each ranked 1 out of 5), and most trials did not provide information on dietary intake or adherence to dietary prescription, making it challenging to assess the impact of diet. Future trials should monitor and report intervention adherence.

## 4.3 Implications

The limited number of trials included in the current study limits the capacity to discern the optimal exercise prescription for improving cardio-metabolic health in overweight and obese adolescents. However, the findings are of importance in the context of public health. Exercise plays an important role in maintaining cardio-metabolic health, beyond maintenance of body weight or BMI.[58] This section discusses how exercise interventions may fit within a broader prevention strategy, and the particular importance of primary healthcare providers. New Zealand is used as an exemplar context to guide the discussion. While it is difficult to generalize this discussion to all Western nations, New Zealand is a relatively contained Westernized country and may provide important signposts for other developed nations, or at the least this section may stimulate necessary dialogue.

### 4.3.1 Primary Health Care Providers

Primary healthcare providers are at the coalface and uniquely positioned to tackle inactivity, but the following factors need to be considered: (i) the appropriate amount and form of exercise prescription, (ii) the medical education required for prescribing exercise or referring to an exercise specialist, and (iii) the appropriate outcomes for monitoring success.

In support of findings from the current meta-analysis, dietary modification has previously been reported to be relatively ineffective in the long-term treatment of obesity in adults.[59, 60] However, findings from this meta-analysis do suggest that exercise plus dietary co-intervention is superior for weight loss, at least short-term. Further, exercise intervention may also be important for improving other cardio-metabolic risk factors. With regards to exercise prescription, the WHO recommends that children aged 6-17 years participate in at least 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) every day.[61] However, obese adolescents are disadvantaged by physical and cardiovascular constraints, simply due to the effort and pain associated with moving a large mass. A meta-analysis of exercise treatment programmes in obese children and adolescents has shown that the most effective exercise paradigm for improving body composition incorporates high repetition resistance training combined with low-intensity aerobic exercise and behavioural modification.[62] While the current meta-analysis lacked a sufficient number of trials to perform sub-group analysis on the cardio-metabolic benefits of aerobic versus strength training, a recent study reported that obese individuals with high strength fitness exhibit cardio-metabolic risk profiles similar to normal-weight, fit individuals.[47] Similarly, normalized muscle strength has recently been inversely associated with cardio-metabolic risk in in 1421 boys and girls.[63] Further investigation is required to confirm these findings in obese adolescents, as well as determine the additive benefits of dietary modification.

In terms of medical training within New Zealand, as per other parts of the world exercise prescription is not a formal part of medical school education. In line with studies conducted elsewhere, it is likely that New Zealand-based primary healthcare practitioners are unfamiliar and uncomfortable with exercise prescription.[64, 65] One solution is to implement exercise prescription/behavioral medicine into medical education programmes. Another is to provide an integrated system for prescribing and implementing exercise solutions. Green prescription (GRx) was adopted in 1998 in New Zealand, which provides general practitioners and practice nurses the ‘option’ of referring patients to an exercise physiologist where it may be considered beneficial to patients who are overweight or have a stable medical condition. However, the initiative only reached 32,285 patients in 2012-13, does not provide prescription education to general practitioners or nurses, and is limited to adults 18 years or older. New Zealand’s neighbour, Australia,[66] along with 38 other countries,[64] has adopted Exercise is Medicine (EIM). The primary goal of EIM, which was established by the American College of Sports Medicine (ACSM) in 2007, is to make exercise a standard part of the medical paradigm for the prevention and treatment of NCDs in healthcare systems.[64, 65] EIM extends the GRx initiative by including the establishment of a multi-sectorial taskforce in each country, a specific paediatric initiative, providing an EIM credential for practitioners, development and training of a community-based referral network, and integration with an electronic medical records system.[64, 67]

With regard to assessing the appropriate health outcome, there has been debate as to whether “cardiorespiratory fitness” or “fatness” is the strongest correlate of cardio-metabolic health. Unfortunately, the current meta-analysis included only 6 trials [26, 28, 31-33, 35] with a measurement of fitness, all of which were suboptimal, precluding analysis of the relative importance of physical fitness and body fatness to cardio-metabolic health in adolesecents. While it is well accepted that physical fitness is a more important correlate of cardio-metabolic health in adults,[68] only one comprehensive study has been conducted in children, reporting that fatness was the strongest correlate of cardio-metabolic risk factors.[69] However, the aforementioned study was criticized for methodological weaknesses[70] and further work is required.[71] Nonetheless, there has been a recent call to emphasize cardiorespiratory fitness over fatness in New Zealand children, particularly when the measure of fatness is BMI.[72] This call[72] championed the use of a simple run test, which can be conducted in schools and administered simultaneously on a large group of children. However, while fitness testing may be appropriate when aerobic exercise is prescribed, such a tool may be insensitive to strength training.[73] Further research is warranted to determine the viability and clinical value of such alternative health outcomes, including when strength training is a component of the prescribed exercise.

In addition to improvements in systolic blood pressure, the current meta-analysis found improvements in the capacity to regulate glucose, and previous studies indicate that exercise intervention improves blood lipids.[48] These markers may be especially important if strength training is prescribed, whereby both BMI and cardiorespiratory fitness testing may prove insensitive. Blood pressures are easily obtainable and are valid and reliable under standardized conditions.[74] However, blood samples are not part of routine assessment for children and adolescents, and invasive blood draws may be unappealing. Fortunately, recent advancements enable blood lipids to be collected with acceptable validity using finger prick devices.[75] Further, valid finger prick devices are able to measure glycated hemoglobin (HbA1c), which may serve as a suitable alternative to an OGTT or the HOMA index.[76]

### 4.3.2 Complex Systems Approaches to Prevention

The section above discussed ground-level approaches to increase exercise prescription and physical activity. At the national policy level, a number of initiatives have been trialled in New Zealand to improve physical activity and reverse the obesity trend, including GRx (see above) and Healthy Eating - Healthy Action. However, despite these policy initiatives to tackle obesity and inactivity, prevalence continues to increase. The Healthy Families NZ initiative is currently being implemented and arguably presents an improved opportunity for success - if it is able to be sustained within communities and within government policy priorities in the longer-term.[77]

In 2015 the New Zealand Government allocated $40 million over four years to support the implementation of Healthy Families NZ. This initiative involves a dedicated health promotion effort in 10 locations across New Zealand, and is expected to reach approximately 900,000 people.[77] The overarching goals of Healthy Families NZ are to reduce the incidence and impact of NCDs through increasing physical activity, improving nutrition, and reducing obesity, tobacco consumption and harmful alcohol use. This initiative is informed by and modelled on the Healthy Together Victoria initiative,[78] which is achieving large-scale reach across the population of Victoria in Australia. Like Healthy Together Victoria, Healthy Families NZ is taking a unique ‘complex systems approach’ [79] to reducing population level NCD risk. Just as important, both of these initiatives include external evaluation to understand, measure, assess and communicate outcomes.

A complex systems approach means considering how the systems that influence health interact to produce outcomes at different social levels, for example in individuals or populations.[79] Such an approach recognizes that even if obesity is the most important determinant of cardio-metabolic health, complex interactions between lifestyle factors and the physical and social environment exist.[79] For example, inadequate sleep may elevate appetite[80, 81] and decrease subsequent daily physical activity.[80-82] Active transport to school, to promote physical activity, may negatively impact nutritional behavior if the food environment on the journey to school is obesogenic.[83] The complex systems approach is in-line with the growing body of evidence demonstrating that community change and health education programmes are unlikely to be successful if they are implemented in isolation of other interventions, including those addressing social determinants.[84]

## 4.4 Limitations

Several limitations should be borne in mind when considering the findings of this meta-analysis. First, the sample size of included trials was generally small, and a limited number of trials reported cardio-metabolic variables. Second, the small number of trials limits the conclusions drawn from the sub-group analysis; further trials are required to more clearly delineate the interactions between exercise and nutrition therapies. Third, the majority of the trials were mixed-sex, and it remains unclear whether both sexes respond similarly. Fourth, the quality of the included trials was generally suboptimal, and lacked information on intervention adherence as well as actual physical activity levels and dietary behaviours. Fifth, only six trials included a measurement of cardiorespiratory fitness, all of which were suboptimal, which would have aided in interpreting the quality of the exercise intervention.

# 5 Conclusions

The current evidence suggests exercise intervention in overweight-obese adolescents improves body composition, particularly decreased body fat mass. The limited available evidence further indicates that exercise intervention may improve some cardio-metabolic risk factors. These findings have implications for (i) primary health care providers, and (ii) public health policy. In terms of primary healthcare providers, BMI may be unsuitable for assessing the efficacy of certain forms of exercise prescription, particularly those with a strength training component. In addition, simple measures of cardio-metabolic health may aid in interpreting the efficacy of exercise intervention. In terms of public health policy, obesity should not be considered in isolation, i.e., there is an apparent need for complex systems models. To achieve long-term, sustainable change consideration needs to be given to the environmental, social and economic determinants of affected populations.

**Compliance with Ethical**

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### Conflicts of Interest

Lee Stoner, David Rowlands, Ariel Morrison, Daniel Credeur, Michael Hamlin, Kim Gaffney, Danielle Lambrick and Anna Matheson declare that they have no conflicts of interest relevant to the content of this review.

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**Figure Legends**

**Fig. 1** Flow diagram of study selection

**Fig. 2** Meta-analysis of studies comparing (a) exercise plus nutrition, (b) exercise only and (c) nutrition only interventions, with changes in body mass index (BMI, kg/m2). The dashed vertical line indicates the mean difference (effect size).

CI, confidence interval; IV, inverse-variance method; SD, standard deviation; SMD, standardized mean difference; SMD qualified effect size bins <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large

**Fig. 3** Meta-analysis of studies comparing (a) exercise plus nutrition, (b) exercise only and (c) nutrition only interventions, with changes in body weight (kg). The dashed vertical line indicates the mean difference (effect size).

CI, confidence interval; IV, inverse-variance method; SD, standard deviation; SMD, standardized mean difference; SMD qualified effect size bins <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large

**Fig. 4** Meta-analysis of studies comparing (a) exercise plus nutrition, (b) exercise only and (c) nutrition only interventions, with changes in body fat (%).The dashed vertical line indicates the mean difference (effect size).

CI, confidence interval; IV, inverse-variance method; SD, standard deviation; SMD, standardized mean difference; SMD qualified effect size bins <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large

**Fig. 5** Meta-analysis of studies comparing (a) exercise plus nutrition, (b) exercise only and (c) nutrition only interventions, with changes in total lean tissue (kg). The dashed vertical line indicates the mean difference (effect size).

CI, confidence interval; IV, inverse-variance method; SD, standard deviation; SMD, standardized mean difference; SMD qualified effect size bins <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large

**Table Legends**

**Table 1** Characteristics of the included studies

AE, aerobic; DXA, dual x-ray absorptiometry; BM; behaviour modification; BMI; body mass index; ER; energy restriction; F, female; PE, physical education; NE, nutrition education; NR, not reported; RT; resistance training; SD, standard deviation; ST, strength training

**Table 2** The effects of exercise intervention

AUC, area under the curve; BMI; body mass index; BP, blood pressure; CI, confidence interval; OGTT, oral glucose tolerance test; HDL, high density lipoprotein cholesterol; HOMA, homeostasis model assessment; LDL, low density lipoprotein cholesterol; SMD, standardized mean difference; SMD qualified effect size bins <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large; inferential likelihoods are unclear if the confidence interval included both substantial positive and negative values (i.e., >5% probability that the true value is greater than both SMD +0.2 and -0.2), otherwise, the likelihood of a worthwhile effect was calculated from the two-tailed t-distribution: 0.5%, almost certainly not; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most certain.

**Table 1** Characteristics of the included exercise intervention trials

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Reference | Quality | Country/setting | Body Composition | BMI | Sample [n (total/F); age (y, mean (SD or range); race] | Intervention | Supervision | Control | Nutrition arm (n) | Duration (wk) |
| Balagopal P, George D, Patton N, et al. [25] | 5 | US/hospital | BMI, DXA | >30 kg/m2 | 15/7; 16(1.1); NR | AE 3x/wk-45 min + NE | Yes, 1x/wk | Usual care | No | 12 |
| Ben Ounis O, Elloumi M, Zouhal H, et al. [26] | 1 | Tunisia/school | BMI, skinfolds | >97 % | 28/14; 13(0.7); NR | AE 4x/wk--90 min + ER | Yes | Usual care | No | 8 |
| Davis JN, Kelly LA, Lane CJ, et al. [23] | 3 | US/laboratory | BMI, DXA | >85 % | 33/16; 16(1.0); Latino | ST 2x/wk-1 h + NE 1x/wk-1.5 h | Yes, 3:1 child/trained ratio | Usual care | Yes (21) | 16 |
| Davis JN, Tung A, Chak SS, et al. [24] | 3 | US/laboratory | BMI, DXA | >85 % | 16/16; 15(1.1); Latino | ST 2x/wk-1 h + NE 1x/wk-1.5 h | Yes, 3:1 child/trained ratio | Usual care, | Yes (10) | 16 |
| Davis JN, Tung A, Chak SS, et al. [24] | 3 | US/laboratory | BMI, DXA | >85 % | 22/22; 15(1.1); Latino | AE + RT 2x/wk-1 h + NE 1x/wk-1.5 h | Yes, 3:1 child/trained ratio | Usual care | Yes (10) | 16 |
| Kim ES, Im JA, Kim KC, et al. [27] | 1 | Korea/school | BMI | 29.5 kg/m2 | 26/0; 17(0.6); NR | AE (jump rope) 5x/wk-40min | Yes | Usual care | No | 6 |
| Lee KJ, Shin YA, Lee KY, et al. [28] | 1 | Korea/school | BMI | >25 kg/m2 | 18/18; 15(0.9); NR | AE (jump rope) 4x/wk-40min | Yes, PE instructor | Usual care | No | 12 |
| Melnyk BM, Small L, Morrison-Beedy D, et al. [29] | 2 | US/school | BMI | >25 kg/m2 | 12/11; 16(0.8); Black/Caucasian | AE 3x/wk-40 min + BM | Yes, 2 | Red cross | No | 9 |
| Meyer AA, Kundt G, Lenschow U, et al. [30] | 1 | Germany/NR | BMI | >97 % | 67/33; 14(2.3); NR | AE 3x/wk-1-1.5 h | Yes, coaches + physiotherapists | Usual care | No | 36 |
| Rocchini AP, Katch V, Schork A, et al. [31] | 1 | US/hospital | BMI, Hydrostatic | >75 % | 35/NR; 12(10-16); NR | AE 3x/Wk-40 min + ER/NE | NR | Usual care | No | 20 |
| Sun MX, Huang XQ, Yan Y, et al. [32] | 1 | China/school | BMI, DXA | >85 % | 42/17; 14(0.7); NR | AE 4x/wk-1 h | NR | NR | Yes (22) | 10 |
| Sun MX, Huang XQ, Yan Y, et al. [32] | 1 | China/school | BMI, DXA | >85 % | 46/27; 14(0.7); NR | AE 4x/wk-1 h + ER | NR | NR | Yes (22) | 10 |
| Toulabi T, Khosh Niyat Nikoo M, Amini F, et al. [33] | 1 | Iran/school | BMI | >28 kg/m2 | 152/mixed; 16(1); NR | AE 3x/wk-60 min + BM | NR | NR | No | 12 |
| Tsang TW, Kohn M, Chow CM, et al. [34] | 5 | Australia/hospital | BMI, DXA | >85 % | 20/12; 13(1.8); MR | AE (Kung Fu) 3x/wk-1 h | Yes, 1 instructor per class | Tai Chi 3x/wk-1 h | No | 36 |
| Wong PC, Chia MY, Tsou IY, et al. [35] | 1 | Singapore/school | BMI, DXA | >25 kg/m2 | 24/0; NR(13-14); NR | Extra PE (AE + ST) 2x/wk-55 min | Yes, trained PE teachers | Usual care | No | 12 |

AE, aerobic; DXA, dual x-ray absorptiometry; BM; behaviour modification; BMI; body mass index; ER; energy restriction; F, female; PE, physical education; NE, nutrition education; NR, not reported; RT; resistance training; SD, standard deviation; ST, strength training

**Table 2** The effects of exercise intervention, alone or combined with other lifestyle interventions

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Outcome | Trials (n) | Sample (n) | Mean difference | |  | SMD | |  | Inference | |  | Heterogeneity | |
|  |  |  | Pooled difference | |  | Pooled difference | |  | p-value | Likelihood |  | I2 (%) | p-value |
|  |  |  | (95% CI ) | |  | (95% CI ) | |  |  |  |  |  |  |
| Fitness | 7 [26, 28, 30-32, 35] | 260 | - |  |  | 1.27 | (0.97, 1.57) |  | <0.001 | Most certain |  | 94 | <0.001 |
| BMI | 15 [23-35] | 554 | 2.04 | (1.54, 2.53) |  | 0.47 | (0.36, 0.58) |  | <0.001 | Most certain |  | 54 | 0.007 |
| Weight (kg) | 14 [23-29, 31-35] | 487 | 3.70 | (1.65, 5.75) |  | 0.28 | (0.12, 0.44) |  | <0.001 | Most certain |  | 0 | 0.657 |
| Body fat (%) | 13 [23-28, 30-32, 34, 35] | 391 | 3.14 | (2.15, 4.13) |  | 0.35 | (0.24, 0.46) |  | <0.001 | Most certain |  | 56 | 0.007 |
| Total lean (kg) | 12 [23-28, 31, 32, 34, 35] | 324 | 1.57 | (0.53, 2.61) |  | 0.10 | (0.03, 0.17) |  | 0.003 | Most certain |  | 56 | 0.008 |
| Waist (cm) | 6 [27, 28, 32-34] | 303 | 3.02 | (1.25, 4.79) |  | 0.32 | (0.13, 0.51) |  | <0.001 | Most certain |  | 0 | 0.818 |
| Systolic BP (mm Hg) | 4 [27, 30, 31, 35] | 152 | 7.08 | (3.49, 10.7) |  | 0.60 | (0.30, 0.90) |  | <0.001 | Most certain |  | 84 | <0.001 |
| Total cholesterol (mg/dl) | 5 [27, 28, 32, 35] | 156 | 5.79 | (-2.16, 13.7 |  | 0.20 | (-0.07, 0.47) |  | 0.153 | Unclear |  | 0 | 0.866 |
| Triglycerides (mg/dl) | 6 [27, 28, 30, 32, 35] | 223 | 9.18 | (-2.85, 21.2) |  | 0.23 | (-0.07, 0.53) |  | 0.135 | Unclear |  | 0 | 0.887 |
| HDL cholesterol (mg/dl) | 6 [27, 28, 30, 32, 35] | 217 | 0.20 | (-1.18, 1.57) |  | 0.02 | (-0.12, 0.16) |  | 0.870 | Unclear |  | 0 | 0.636 |
| LDL cholesterol (mg/dl) | 5 [27, 30, 32, 35] | 205 | 5.83 | (-1.20, 12.9) |  | 0.02 | (0.00, 0.05) |  | 0.104 | Likely |  | 0 | 0.673 |
| Fasting glucose (mg/dl) | 8 [23, 24, 27, 31, 32, 35] | 244 | -1.30 | (-2.78, 0.18) |  | -0.16 | (-0.34, 0.02) |  | 0.146 | Unclear |  | 19 | 0.279 |
| Fasting insulin (*μ*U/ul) | 8 [23, 24, 27, 30-32] | 287 | 0.72 | (-0.89, 2.33) |  | 0.17 | (-0.21, 0.55) |  | 0.382 | Unclear |  | 71 | 0.001 |
| HOMA | 8 [23, 24, 27, 30-32] | 287 | 1.02 | (0.66, 1.39) |  | 0.40 | (0.26, 0.54) |  | <0.001 | Most certain |  | 88 | <0.001 |
| OGTT glucose AUC (mg/dl) | 3 [23, 24] | 71 | 39.0 | (9.40, 68.6) |  | 0.59 | (0.14, 1.04) |  | 0.010 | Very likely |  | 0 | 0.601 |
| OGTT insulin AUC (*μ*U/ul) | 4 [23, 24, 31] | 106 | 162.0 | (93.3, 231 |  | 0.85 | (0.49, 1.21) |  | <0.001 | Most certain |  | 0 | 0.866 |

AUC, area under the curve; BMI; body mass index; BP, blood pressure; CI, confidence interval; OGTT, oral glucose tolerance test; HDL, high density lipoprotein cholesterol; HOMA, homeostasis model assessment; LDL, low density lipoprotein cholesterol; SMD, standardized mean difference; SMD qualified effect size bins <0.2 was defined as trivial, 0.2–0.3 as small, 0.4–0.8 as moderate and >0.8 as large; inferential likelihoods are unclear if the confidence interval included both substantial positive and negative values (i.e., >5% probability that the true value is greater than both SMD +0.2 and -0.2), otherwise, the likelihood of a worthwhile effect was calculated from the two-tailed t-distribution: 0.5%, almost certainly not; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most certain.