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A rationale and method for high-intensity progressive resistance training with children and adolescents

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Abstract

Background: The rising prevalence of obesity in children and adolescents is implicated in the metabolic abnormalities that track into adulthood. The associated increased incidence of insulin resistance, metabolic syndrome and type 2 diabetes being identified in younger cohorts has given rise to a critical global health issue. Muscular strength is a vital component of metabolic fitness that provides protection from insulin resistance in adults, and we have recently shown this to be true in children as well. Targeting muscular strength deficiencies at an early age may be an effective preventative strategy for metabolic syndrome and type 2 diabetes.
Purpose: There is limited evidence-based best practice for progressive resistance training (PRT), adiposity and metabolic fitness in children and adolescents. The purpose of this paper is to describe the methodology we utilized for implementing a PRT program to avoid publication bias, enable replication of the study and share a novel program that we have found safe and suitable for use with youth.
Methods: We conducted the first randomized controlled trial (RCT) prescribing high-intensity PRT to children and adolescents (10–15 years) as a community-based primary prevention program to address adiposity and metabolic health. Participants were instructed to complete 2 sets of 8 repetitions of 11 exercises targeting all the major muscle groups twice a week at an RPE of 15–18 for 8 weeks.
Results: Primary outcome was waist circumference; secondary outcomes included insulin resistance, lipid levels, muscle strength, cardiorespiratory fitness, body composition, self-efficacy, self-concept, habitual physical activity, nutritional and sedentary behavior patterns.
Conclusion: The supervised PRT program that we used with children and adolescents has been described in detail. The efficacy of this modality of exercise for metabolic fitness and other health outcomes is now under investigation.

Keywords: Weight training; Pediatric; Diabetes; Obesity; Insulin resistance; Primary prevention; Strength; 1RM; Children; Adolescent; Randomized controlled trial

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1. Introduction

Obesity and its metabolic consequences are global health issues affecting young people at an escalating rate. Although the morbidity and mortality burden is well documented in adults, the body of evidence in children and adolescents is still developing. Turnbull et al. [1] reported that the number of overweight or obese 11–12 year olds in a New Zealand population had doubled in the last decade, a trend echoed in other countries [2,3]. Data suggests that obesity in childhood, and particularly in adolescence, is a strong predictor of obesity in adulthood [4].

The rising prevalence of obesity in children and adolescents is implicated in both the metabolic abnormalities tracking into adulthood and also the increased incidence of insulin resistance, metabolic syndrome and type 2 diabetes identified in younger cohorts [5]. Although global projections forecast a doubling in the prevalence of type 2 diabetes in all age groups from 2000 to 2030 it is likely to be an underestimation if obesity rates continue to rise [6]. Fasting hyperinsulinemia and insulin resistance affect a substantial proportion of overweight/obese children [5], and thus evidence-based prevention strategies, starting in childhood, are of critical public health importance.

We have recently shown that muscular strength is a vital component of metabolic fitness, providing protection from insulin resistance in a New Zealand population of 10–15 year olds [7], exhibiting a similar relationship to that identified in a large adult study conducted in the USA [8]. Of particular interest is that children in both the highest and middle tertiles of absolute upper body strength were 98% less likely to have high insulin resistance compared to those with the lowest strength, after adjustment for central adiposity, body mass and maturation [7]. The importance of muscular strength as an essential component of fitness in children and adolescents is also evidenced by its inclusion in the recent youth guidelines for physical activity [9].

Position statements from many national organizations advocate the use of supervised resistance training with children and adolescents. However, there are only a small number of randomized controlled trials (RCTs) that have investigated both adiposity and the metabolic outcomes of progressive resistance training (PRT). The four RCTs that have addressed both of these domains have all utilized circuit training [10–13], for the delivery of the PRT and three [10,12,13] of these studies included a dietary intervention in addition to the PRT, making it difficult to ascertain the individual contribution of each component of the intervention. Resistance training with children and adolescents has almost always been prescribed as an adjunct to aerobic training or dietary intervention and very often delivered using low-moderate intensity, fast paced training with machines or using body weight.

Higher intensity resistance training may provide equal or greater metabolic benefit than other forms of exercise, including low-intensity PRT [14]. For example Dunstan et al. found that high-intensity resistance training provided greater glycemic control than in an earlier study where older adults with type 2 diabetes completed circuit training [15,16]. Similarly, no studies of low-intensity PRT show change in adiposity or improved insulin sensitivity [17] whereas high-intensity PRT has been shown to reduce visceral fat [18] and insulin resistance [16,19] in normal, obese, and diabetic adults. Cauza et al. [20] have recently shown in the only published RCT to directly compare the two modes of exercise (aerobic vs. strength) in adults with type 2 diabetes, that PRT is superior to aerobic training for metabolic outcomes.

To our knowledge there are no randomized controlled trials of high-intensity PRT as an isolated intervention with children and adolescents that have investigated the effects on insulin resistance alone or in combination with adiposity. There are also no randomized controlled trials of isolated interventions using high-intensity PRT to address obesity in children and adolescents. One previous study [21,22] investigated the use of variable intensities of upper body resistance training and adiposity with children using a small sample in each of the four training groups ($n=11–16$), and although the resistance training intervention groups were randomized the control group ($n=12$) was not. Based on our review of previous literature in children and adults, we thus proposed that supervised high-intensity PRT in a community setting would be a novel, safe and effective strategy for the prevention of risk factors for type 2 diabetes in children and adolescents aged 10–15 years.

We designed a randomized controlled trial to test the hypothesis that our PRT program would be safe to perform, feasible to administer, and beneficial in improving muscular strength and associated metabolic health-related adaptations in this pediatric population. Our methodology for this PRT program is described in detail for 3 reasons: (i) to enable replication of this novel primary prevention intervention in other community based or clinical settings with children and adolescents; (ii) to publicize the design of the trial and associated pre-determined outcomes prior to publication of the results to: prevent publication bias [23,24], enable the reader to readily compare planned and actual implementation [23], to signal an upcoming study for inclusion in systematic reviews [23]; and (iii) to share in a timely fashion a program we

have found to be safe and suitable for use in children and adolescents at a time when obesity and associated metabolic consequences are rising rapidly. This is important, as there is a lack of health-related data available from robustly designed studies to provide evidence-based best practice in relation to PRT and both obesity and metabolic fitness in this population.

2. Methods

2.1. Setting and study design

The present randomized controlled trial (RCT) was conducted in a community setting (a local gym) in a small rural town in Southland, New Zealand with a population of approximately 9900. Ethical approval was granted by the New Zealand Health Research Council and The University of Sydney Ethics Committees. Dual written informed consent was obtained from both parents and participants.

The initial phase of the study involved a RCT comparing a no treatment waitlist control group with those receiving the progressive resistance training (training group) for 8 weeks. Concealed randomization using a computer-generated list stratified for age and gender was carried out by an independent person and used to allocate participants to either the no-treatment control or PRT group after baseline testing had been completed. Randomization took place between September 2003 and July 2004. The study was registered by the Australian Clinical Trials Registry (ACTR), ACTRN012605000102673, (http://www.actr.org.au).

Following the initial phase of the study those randomly assigned to the control group were invited to crossover to PRT for 8 weeks while the training group continued for an additional 8 weeks (16 weeks total). This crossover design was utilized to avoid disappointment in the children and adolescents who were all in the same schools as those who were training, and because the long-term aim of the community program was to increase exercise and decrease metabolic risk. In addition to the RCT and crossover study, the program has continued to be offered as a community program to youth aged 10–15 years with progress monitored each school term (9–10 weeks).

2.2. Recruitment of potential participants

The Intermediate and High Schools ($n=3$) in the area were approached to invite them to be involved, and two out of three agreed. All students at the two schools who were in Year 7–10 (approximately 10–15 years of age) were invited to participate ($n=491$). The children and adolescents were told about the project at school assembly, information went home to parents in the school newsletter and the children and adolescents took home an information letter, consent form and medical history form. The study investigators were available to answer any questions after the school assemblies, by telephone and at a parent and child information evening. Those who agreed to participate returned their consent and medical form by post or via the drop box at their school.

The inclusion criteria for the study were: in year 7–10 in the study area with completed consent and medical forms. Exclusion criteria were: risk factors identified on the medical form that may lead to physical injury or adversely affect health (with no subsequent clearance by their physician), on medications that affect heart rate, severe cognitive impairment or inability to adequately understand English (as there was no interpreter available) that would affect participant safety and ability to understand verbal instructions.

2.3. The medical screening process

On receiving the returned consent and medical forms those that had any potential medical issues identified or incomplete information were followed up by phone for clarification and to assess suitability for the study. The majority of medical follow-up was a result of incomplete or insufficient information on the medical form. The two most common items needing clarification were: 1) status of reported musculoskeletal injuries and 2) exercise restrictions related to asthma status and inhaler usage.

2.4. Outcome measures

All baseline data was collected prior to randomized group allocation. Primary and secondary outcome measures are listed below and utilized validated protocols. The primary outcome was blinded to the researchers. *Primary*

outcome: waist circumference. *Secondary outcomes*: height, weight, body mass, maturation, bioelectrical impedance (BIA) estimation of fat and fat-free mass [25], 1 repetition maximum (1RM) bench press and leg press [7], blood analysis with external quality assurance run for the laboratory by Royal College of Pathologists Australasia (lipids, insulin, glucose), VO_2 peak [26], physical activity, sedentary activities, nutritional habits [27], self-efficacy [28] and self-concept [29]. Insulin resistance was estimated from the fasting insulin and glucose values using the Homeostasis Assessment Computer Model2 (HOMA2-IR) [30–32].

2.5. Sample size

Power calculations were based on the primary outcome waist circumference; predicted effect size = 0.91 (difference between groups = 1 cm ± 2.2 cm), beta = 0.05, alpha = 0.05, using estimates from the literature reporting the effect of PRT on WC [33]. There were no exact data in children so an adult estimate of effect size was conservatively reduced given the lower doses of exercise that the participants in this study would be exposed to, with the same SD retained. We estimated that 33 participants would be needed for each of the 2 groups ($n = 66$). To account for potential attrition (15%) a sample of 76 was targeted for recruitment.

2.6. Statistical analysis

All data will be analyzed using SPSS vers.11 for Mac (SPSS Inc., Chicago, Il.). Group differences (control vs. training) will be checked at baseline and descriptive data will be presented as mean (SD) or median (range) as appropriate and log values will convert non-normally distributed data. Differences in primary and secondary outcomes between control and training groups will be compared using per-protocol analysis to provide information about the efficacy of the study, with participants who were lost to follow-up or did not complete the intervention excluded from the analysis. The rational for per-protocol analysis is the novelty of the study and the need to understand if an intervention has a potential to modify risk factors before the effectiveness of dissemination is assessed [34]. Secondary analysis will compare the per-protocol (efficacy) analysis with intention-to-treat (effectiveness) analysis with data brought forward from the last time point for any missing data. Regression analysis will identify any baseline, adherence, or change in other factors contributing to the waist circumference changes.

Age and gender, factors in randomization stratification, as well as maturation will be considered as potential covariates for adjusted analysis. A two-tailed p value of < 0.05 will be accepted as statistically significant, for primary outcomes; Bonferroni adjustment of p values will be applied as appropriate for secondary outcomes.

2.7. The progressive resistance training program

The intervention was designed around the cognitive behavioral perspective and incorporated social cognitive theory as an integral part of the adherence program and participant recording of training data [35]. This study was grounded in stimulus control theory [35] with an environment created that gave immediate positive reinforcement, corrective feedback and verbal and visual cues throughout each training session. Achievable progressive short-term goals to develop confidence in participant abilities and develop self-efficacy were offered. These behavioral theories were operationalized in this study through the use of mirrors, technique based certificates, random prize draws for sustained attendance, self-monitoring of training attendance and recording of training data (weight lifted, reps, rating of perceived exertion (RPE) [36],) each session to optimize internalization of this new behavior.

2.7.1. PRT equipment

The PRT was implemented using free-weights (dumbbells and bars) and weighted ankle cuffs (Australian Barbell Company, Mordialloc, VIC, Australia; York Barbell Co. Ltd, Toronto, Canada). Body weight was used initially for the abdominal exercises with progression utilizing dumbbells, weight plates and weighted ankle cuffs. The dumbbells and weight plates were stored on racks with the ankle weights kept in a box on wheels for easy manoeuvrability from storage to the training area. Although the current RCT was conducted in a gym setting the program was designed to enable its use in any setting with minimal large equipment being required. A squat rack

and bench were the largest pieces of equipment used facilitating portability to any location (e.g. school, hall, classroom sized space). We used the gym setting (there was only one local gym) as it enabled us to use existing equipment available in the community with the exception of the weighted ankle cuffs. Participants made their own way to the training venue, usually using the same mode of transport as that used to and from school and was within walking distance (<2 km).

2.7.2. Specific PRT exercises

A total of 11 exercises designed to target all of the major muscle groups were prescribed each training session. The upper body exercises included the bicep screw curl, triceps extension, one arm dumbbell row, one dumbbell front raise, and bench press, (Fig. 1). Lower body exercises included standing leg abduction, standing leg curl, calf raise and lower, and squat (Fig. 2). The abdominal muscles were targeted with the abdominal crunch and abdominal reverse crunch (Fig. 3). We initially used the triceps kickback as the prescribed triceps exercise but as the program has continued in the community we have substituted and rotated the triceps exercise that is prescribed during the year. We selected from triceps kickback, modified triceps extension, french press or double arm triceps extension to add some variety without compromising safety, form and information overload for the participants.

Fig. 1. Upper body progressive resistance training exercises — one dumbbell front raise, bicep screw curl, bench press, triceps kickback, one arm dumbbell row.

Fig. 2. Lower body progressive resistance training exercises — standing leg curl, standing leg abduction, calf raise and lower, squat.

2.7.3. Mode of delivery, frequency, intensity, volume and progression

The PRT was delivered to participants as a group of 15–25 with all the prescription provided on an individual basis, determined initially by 1RM pre-testing and then based on the previous training session data (RPE, weight, sets, reps). Participants exercised twice a week under the supervision of an exercise physiologist with previous experience working with children and adolescents with assistance from additional trained personnel to maintain a 1:4 supervision ratio. The ratio was higher during the initial learning phase when all of the participants were new. We have found that when participants have established correct form it is possible to safely decrease the ratio to 1:5 or 1:6 depending on the social and behavioral needs of the participants in the group.

During each training session, two sets of 8 repetitions of the 11 exercises were performed at a rating of perceived exertion (RPE) of 15–18 on the 6–20 Borg scale [36]. In order to maintain this prescription the training loads were adjusted on an individual basis as participant's strength improved.

Throughout each session form was monitored and corrected as necessary with an emphasis on exercises being performed slowly. Safety was monitored using an adverse events form. A multi-modal method of disseminating information and corrective feedback, (kinaesthetic, visual and auditory), was utilized to cater for the different learning styles of the participants because of their young age. A3 posters with pictures showing correct technique, instructions for the exercise, the muscles being used and a summary of key technique points were displayed at each of the 11 training stations. This was particularly important for those participants who had difficulty reading as it enabled them to

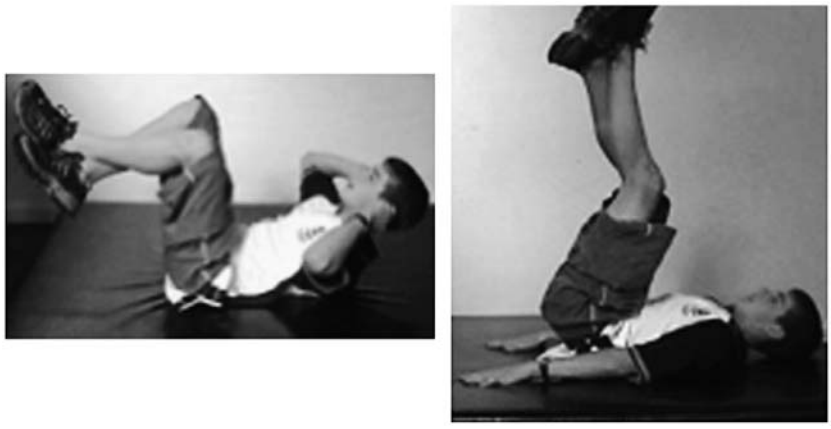

Fig. 3. Abdominal exercises: abdominal crunch and abdominal reverse crunch.

independently match the exercise picture showing technique with the name on the card and then with the same name on their recording sheet.

Each school term (9 or 10 weeks), after 8 weeks of training we provided feedback on training progress in the form of strength improvements, using a 1RM bench press and leg press for the RCT and crossover study and only 1RM bench press for the continuing program. This was contextualized by providing information on adherence (how often the participant trained in relation to the training sessions available) for the continuing program.

For the calf raise and lower exercise (Fig. 2) we established five difficulty levels for two reasons; the first being motivation and secondly to increase the number of stabilizer muscles recruited to correctly perform the exercise. During exercises such as the biceps curl and front raise, postural form was utilized to encourage the use of core stability rather than completing the exercises supported by the back of a bench or wall. The biceps curl was undertaken seated to avoid the recruitment of leg muscles and to discourage the temptation of using incorrect form by utilizing the back muscles to assist in overcoming inertia.

2.7.4. Progress of the study

Recruitment of potential participants for the RCT commenced in 2003 and ended in 2004. 126 potential subjects were screened, and a total of 78 children and adolescents were randomized into the intervention ($n=37$) and control ($n=41$) groups (Fig. 4). No adverse events were documented during testing or training sessions. Compliance to the intervention, as well as primary and secondary outcomes will be available in 2006.

3. Conclusion

This study will provide novel information about the effects of progressive resistance training on obesity and metabolic fitness in children and adolescents. The supervised PRT program that we used with children and adolescents has been described in detail. It may offer a viable alternative to current exercise choices for health promotion in children and young adults at a time when strategies to address the rising prevalence in obesity and its metabolic complications

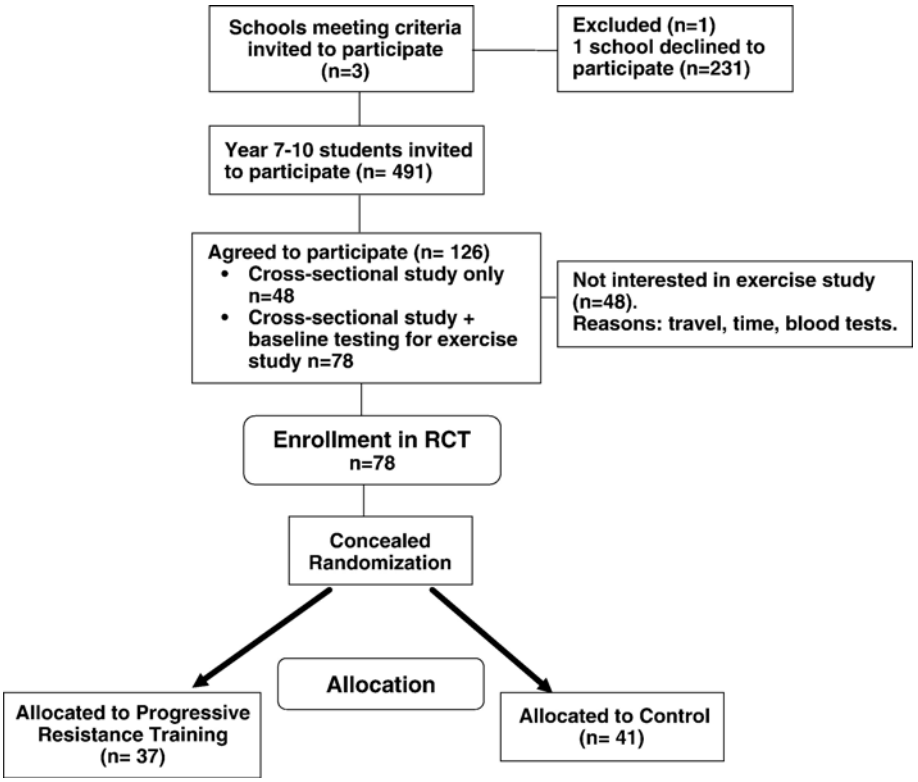

Fig. 4. Recruitment flow.

are needed. We conducted this study in a cohort of healthy weight and overweight/obese individuals; specifically targeting clinical populations in future studies may be indicated.

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