Title: Mediating effects of resistance training skill competency on health-related fitness and physical activity: The ATLAS cluster randomised controlled trial

Running title: Mediating effects of resistance training skills

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Abstract

The purpose of this study was to examine the mediating effect of resistance training skill competency on percent body fat, muscular fitness and physical activity among a sample of adolescent boys participating in a school-based obesity prevention intervention. Participants were 361 adolescent boys taking part in the ATLAS cluster RCT; a school-based program targeting the health behaviours of economically disadvantaged adolescent males considered ‘at-risk’ of obesity. Body fat percentage (bioelectrical impedance), muscular fitness (hand grip dynamometry and push-ups), physical activity (accelerometry), and resistance training skill competency were assessed at baseline and at post-intervention (i.e., 8-months). Three separate multi-level mediation models were analysed to investigate the potential mediating effects of resistance training skill competency on each of the study outcomes using a product-of-coefficients test. Analyses followed the intention-to-treat principle. The intervention had a significant impact on boys’ resistance training skill competency, and improvements in skill competency significantly mediated the effect of the intervention on percent body fat and the combined muscular fitness score. No significant mediated effects were found for physical activity. Improving resistance training skill competency may be an effective strategy for achieving improvements in body composition and muscular fitness in adolescent boys.

Keywords: *adolescent, movement skills, overweight, physical fitness, physical activity*

Introduction

Physical inactivity has been described as a global pandemic (Kohl et al., 2012). International guidelines recommend children and adolescents engage in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) each day, consisting of aerobic activities and activities to strengthen muscle and bone (World Health Organization, 2010). However, recent global estimates show that 80% of adolescents fail to meet this guideline (Hallal et al., 2012). Considering the current and future economic burden associated with physical inactivity, identifying evidence-based strategies to engage young people in health-enhancing physical activity is clearly warranted. Adolescence is a critical developmental window for establishing healthy behavioural habits that may track into adulthood (Sawyer et al., 2012), yet this is also a period during which significant declines in physical activity occur (Sallis, 2000). To promote engagement in a variety of physical activities during adolescence, a more thorough understanding of the mechanisms underpinning physical activity participation is required.

As demonstrated in a recent systematic review (Babic et al., 2014), perceived movement skill competence (hereafter referred to as perceived competence) is a consistent psychological correlate of physical activity in adolescent populations. However, perceived competence is situated within the context of an individual's actual competence in various forms of movement. Stodden et al., (2008) posit that developing actual motor competence provides a foundation for the development of an individual's perceived competence, health-related fitness, physical activity behaviours, and a healthy weight status. During the transition to middle childhood (i.e., 6-9 years of age), children develop the cognitive capacity to more accurately assess their competence in various movement contexts, and this assessment will increasingly influence, either positively or negatively, their motivation to engage in physical activity (Stodden et al., 2008). Consequently, in addition to improving perceived competence, a focus on improving actual movement skills may be crucial to increase motivation in various types of physical activity among adolescents.

Much of the literature regarding movement skill competence has focused on proficiency in fundamental movement skills , a set of skills considered the 'building blocks' for the more complex motor patterns required for successful sports performance (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). While there is evidence for the importance of fundamental movement skill proficiency for physical activity and health-related fitness (Lubans et al., 2010), fundamental movement skills may be a better predictor of organised (i.e., competitive sports) rather than non-organised (i.e., individual fitness activities) physical activities (Okely, Booth, & Patterson, 2001). Given participation rates for organised sports decline during adolescence (Telama & Yang, 2000), competence in motor patterns related to 'lifelong' physical activities (e.g., resistance training, cycling, swimming, yoga etc.) may be required to engage adolescents in ongoing physical activity.

Resistance training refers to a method of conditioning using a variety of resistive loads to achieve improvements in health, muscular fitness, and physical performance (Harries, Lubans, & Callister, 2012; Lloyd et al., 2013) This type of activity may be a convenient substitute for (as well as an adjunct to) organised sport as it can be performed alone, at little or no cost, and with minimal equipment if preferred.

Importantly, the motor coordination patterns required to be successful in this form of activity may be easier to learn than the specialised motor patterns required for success in many sports. Therefore, this form of activity may be an appropriate substitute for youth that have failed to achieve the level of fundamental movement skill proficiency inherently demanded for successful sports performance (Stodden, True, Langendorfer, & Gao, 2013). Additionally, resistance training may be a desirable activity option for sufficiently skilled adolescents that have decided to discontinue participation in organised sport, and for overweight and obese youth who may avoid aerobic-based physical activities

Despite the benefits of resistance training for young people (Lloyd et al., 2013), and its potential as an alternative to organised sport, little research has focused on resistance training-related movement skills and their association with physical activity and health-related fitness. Recently, Lubans and colleagues (Lubans, Smith, Harries, Barnett, & Faigenbaum, 2014) designed a skill assessment battery for evaluating resistance training movement skills - the Resistance Training Skills Battery. The six movements included in this assessment battery (i.e., squat, lunge, push up, overhead press, front support with chest touches, and suspended row) encompass all the major muscle groups and are considered the foundation for more complex movements used in resistance training programs. The importance of resistance training skill competency for health-related fitness and physical activity has not been empirically examined. However, cross-sectional evidence among a small sample of adolescents has demonstrated that resistance training skill competency is associated with muscular fitness (Lubans, Smith, Harries, et al., 2014). Further exploration of these associations using experimental data is warranted. Therefore, the aim of the present study is to examine the potential mediating effects of resistance training skill competency on body composition, muscular fitness and physical activity among a sample of adolescent boys participating in a school-based obesity prevention intervention (Smith, Morgan, Plotnikoff, Dally, Salmon, Okely, Finn, Babic, et al., 2014; Smith, Morgan, Plotnikoff, Dally, Salmon, Okely, Finn, & Lubans, 2014).

Methods

Study design and participants

Participants were 361 adolescent boys (mean age, 12.7 ± 0.5 years) involved in the Active Teen Leaders Avoiding Screen-time (ATLAS) cluster randomised controlled trial ; a school-based obesity prevention trial conducted in 14 secondary schools in low-income areas of New South Wales, Australia. Ethics approval for the study was obtained from the human research ethics committees of the University of Newcastle and the New South Wales Department of Education and Communities. School principals, teachers, parents and study participants all provided informed written consent prior to enrollment in the study. A detailed description of the methodology can be found elsewhere (Smith, Morgan, Plotnikoff, Dally, Salmon, Okely, Finn, Babic, et al., 2014).

Power calculation

Prior to recruitment, a power calculation was conducted to determine the required sample size to detect meaningful changes in the primary outcomes (i.e., body mass index [BMI] and waist circumference) of the ATLAS study. Based on 80% power, an α level of 0.05, an expected drop-out rate of 20%, and a school clustering effect of ICC = 0.03; it was calculated that 350 participants (i.e., 25 per school) would be required to detect a between-group difference in BMI and waist circumference of 0.4 $kg.m^{-2}$ and 1.5 cm, respectively. In addition, the study was adequately powered to detect small to medium-sized mediation effects using a product-of-coefficients test (Fritz & MacKinnon, 2007).

Intervention

The ATLAS intervention was a multi-component, school-based program aimed at improving body composition, muscular fitness and weight-related behaviours (i.e., screen-time, physical activity and sugared beverage consumption) among adolescent boys attending schools in low-income communities. The intervention was underpinned by Self-Determination Theory (Deci & Ryan, 1985) and Social Cognitive Theory (Bandura, 1986). Specifically, the intervention aimed to improve competence, autonomy, and relatedness needs satisfaction during school sport in order to enhance self-determined motivation for physical activity. In addition, the intervention aimed to increase boys' perceived competence and self-efficacy for resistance training exercises through the development of resistance training movement skills. The intervention included researcher-led seminars for students, provision of fitness equipment to schools, a smartphone application and website, pedometers for self-monitoring, parental strategies for reducing screen-time (i.e., newsletters), lunch-time physical activity mentoring sessions, and face-to-face activity sessions run by teachers during the timetabled school sport period. Intervention strategies were aligned with key behavior change techniques. For example, the smartphone application component of the program included strategies for self-monitoring and goal setting and also provided information on the link between health and weight-related behaviours via push prompts (Lubans, Smith, Skinner, & Morgan, 2014). Participating teachers delivered the intervention following a pre-program professional learning workshop conducted by members of the research team. During the school sport sessions, students participated in a range of activities including resistance training circuits, high-intensity fitness challenges, strength and aerobic-based games, and modified ball games. The program focused on improving muscular fitness and students completed both elastic band (i.e., Gymstick™) and body weight (e.g., push-ups) resistance exercises. Finally, a core component of the activity sessions was time dedicated to resistance training movement skill development, during which teachers explained and modelled correct exercise technique and provided corrective feedback to students during their performances. A more detailed description of the intervention, including the resistance training-based school sport sessions, has been reported previously (Smith, Morgan, Plotnikoff, Dally, Salmon, Okely, Finn, Babic, et al., 2014).

Measures

Assessments were conducted by trained research assistants at baseline (November – December, 2012) and 8-months later after the conclusion of the program (July – September, 2013). Demographic information including age, country of birth, cultural background, and language spoken at home was collected via a questionnaire. The Socio Economic Indexes For Areas (SEIFA) Index of Relative Socioeconomic Disadvantage (scale, 1 = *lowest* to 10 = *highest*) (Australian Bureau of Statistics, 2008) was used to determine participant SES. Individual SES was coded as the population decile corresponding to the participant's residential postcode. For interpretation, a value of ≤ 5 indicates the bottom 50% of the socioeconomic distribution.

Height and body mass. Height was recorded to the nearest 0.1 cm using a portable stadiometer (Model no. PE087, Mentone Educational Centre, Australia). Weight was measured to the nearest 0.1kg without shoes, in light clothing using a portable digital scale (Model no. UC-321PC, A&D Company Ltd, Tokyo, Japan). BMI was calculated using the standard equation (weight [kg] / height [m]^2) and weight status was determined using BMI z-scores calculated using the 'LMS' method (WHO growth reference centiles) (Onis et al., 2007).

Body composition. Body fat percentage was assessed using the Imp SFB7 bioelectrical impedance analyser (ImpediMed, Ltd., Eight Mile Plains, Queensland, Australia). The Imp SFB7 is a multi-frequency, tetra polar bioelectrical impedance spectroscopy device and has acceptable test-retest reliability in adolescents (Lubans et al., 2011).

Muscular fitness. The 90-degree push-up test was used as a measure of upper body muscular endurance. Push-ups were performed in time with a metronome, set at 40 beats per minute, allowing one push-up every three seconds. Testing procedures were explained prior to the test. Participants lowered their body in a controlled manner until a 90-degree angle was formed at the elbow then pushed back up. The test concluded when participants either failed to maintain the movement with adequate form in time with the metronome, failed to lower themselves to the required depth on three non-consecutive repetitions, or upon volitional failure. Participants did not receive verbal encouragement during the conduct of the test. This test has acceptable test-retest reliability in adolescents (Lubans et al., 2011). Upper body muscular strength was assessed using a handgrip dynamometer (SMEDLEY'S dynamometer TTM, Tokyo, Japan). After adjusting the grip-span to suit the hand size of the participant, boys were asked to squeeze the dynamometer continuously as hard as possible for three seconds with the elbow in full extension down by the side of the body. The test was performed three times each for the left and right hands, alternating hands after each trial, and the participants score was calculated as the mean of all trials. To provide a measure of muscular fitness encompassing both maximal strength and local muscular endurance, a muscular fitness score was calculated (Artero et al., 2013; Artero et al., 2011). The muscular fitness score was calculated using the results of the two muscular fitness tests. To adjust for differences in body size, hand grip strength was first expressed relative to body weight. The individual scores were then standardised as follows: (value-mean/SD). The muscular fitness score was calculated as the sum of the two standardised scores.

Physical activity. Physical activity was assessed using Actigraph™ accelerometers (model GT3X+). Participants wore their monitors for seven consecutive days, during waking hours except while bathing and swimming. Data were collected and stored in 5-second epochs. Valid wear time was defined as a minimum of three weekdays with at least 8 hours (i.e., 480 minutes) of total wear time recorded, and non-wear time was defined as 30 minutes of consecutive zeroes. Activity counts were categorised into sedentary, light, moderate, and vigorous intensity using the cut points proposed by Evenson et al. (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008). The time (i.e., mean daily minutes) spent in moderate and vigorous intensity activity was summed to produce a measure of moderate-to-vigorous physical activity (MVPA).

Resistance training skill competency. Resistance training skill competency was assessed using video analysis of the Resistance Training Skills Battery (Lubans, Smith, Harries, et al., 2014). Following a demonstration by the assessor, participants performed two sets of four repetitions of each exercise in the order listed (i.e., squat, push up, lunge, overhead press, front support with chest touches, and suspended row) with a rest period of up to 15 seconds between sets. Participants did not receive skill specific feedback during their performance. Each skill consists of four or five performance criteria and is scored by adding the total number of performance criteria successfully demonstrated across the two sets. Consequently, the highest possible score for each skill is 8 or 10 depending on the number of performance criteria. Each of the six skill scores are summed to produce a composite score, termed the Resistance Training Skill Quotient (RTSQ), with a possible range of 0 – 56. The Resistance Training Skills Battery has satisfactory test-retest reliability in adolescents (Typical error of RTSQ [95%CI] = 2.5 [2.1 to 3.0]) (Lubans, Smith, Harries, et al., 2014).

Statistical analyses

For all analyses, statistical significance was set at $P < 0.05$. Cross-sectional associations between study variables at baseline were examined using Pearson's bivariate correlations in SPSS version 20.0 for Windows (2010, SPSS Inc., IBM company Armonk, NY). Mediation analyses followed the intention-to-treat principle, with missing data for percent body fat and muscular fitness imputed using the expectation maximisation method (Dempster, Laird, & Rubin, 1977). Due to the large amount of missing data for MVPA, no imputation was performed for this outcome. Mediation analyses were conducted using a product of coefficients test (Krull & MacKinnon, 2001) in MPlus, version 7.11 for Windows (Muthén & Muthén, Los Angeles, CA). Multi-level linear regression analysis was used to: (i) calculate the regression coefficient for the effect of the intervention on the hypothesised mediator (Pathway A); (ii) determine the association between the mediator variable and the outcome variable at post-intervention, independent of group assignment and baseline values (Pathway B); and (iii) estimate the total (Pathway C) and direct (Pathway C') intervention effects for each study outcome. The direct effect (C') represents the intervention effect controlling for the mediator, or the effect of the intervention on the outcome not explained by the mediated effect. The product of the A and B coefficients was then computed to determine the mediated effect (Pathway AB) and the 'RMediation' package (Tofighi & MacKinnon, 2011) was used to compute the confidence intervals of the mediated effect. Confidence intervals that do not cross zero indicate statistical significance. Three separate single mediator models were tested (Figure 1), one for each outcome (i.e., MVPA, muscular fitness and percent body fat). All models were adjusted for baseline values, participant SES, and school-level clustering. Subgroup analyses were also conducted, with the models repeated separately for boys classified as overweight or obese (combined into a single group) at baseline.

****Figure 1 near here****

Results

In total, 361 boys (mean age, 12.7 ±0.5 years) were assessed at baseline. As shown in Table I, the majority of boys were born in Australia (95%), identified their cultural background as Australian (77%) and spoke English at home (96%). In addition, 85% of boys resided in areas with a SEIFA score less than 5 indicating that the majority were of low-to-middle SES. Further, approximately a third of boys were classified as overweight or obese. Post-intervention assessments for the primary outcomes at 8-months were completed for 293 boys, representing an overall retention rate of 81%. The 8-month study outcomes have been reported previously (Smith, Morgan, Plotnikoff, Dally, Salmon, Okely, Finn, & Lubans, 2014). Briefly, there were no significant intervention effects for body composition, physical activity or grip strength. However, significant group-by-time effects were observed for screen-time (mean = -30 ± 10 mins/d; $P = .03$), push-ups (mean = 0.9 ± 0.5 repetitions; $P = .04$), and sugar-sweetened beverage consumption (mean = -0.6 ± 0.3 glass/d; $P = .01$).

The number of participants with complete data for resistance training skill competency and each outcome was $n = 253$ (70%) for percent body fat, $n = 248$ (69%) for muscular fitness, and $n = 130$ (36%) for MVPA. Baseline and post-test values for study outcomes can be seen in Table II. Pearson's bivariate correlations indicated that resistance training skill competency was significantly associated in the expected direction with percent body fat ($r = -.28$, $P < .001$), muscular fitness ($r = .43$, $P < .001$) and MVPA ($r = .16$, $P = .01$) at baseline.

****Table I and II near here****

Intervention effects (Pathway C)

Results for the action theory test (A), conceptual theory test (B), direct effect (C'), and mediated effect (AB) can be found in Table III. Analyses were first conducted only among those with complete data for the mediator and the outcome, then among the entire sample with missing data imputed. Comparisons of the regression coefficients showed that the magnitude of the effects were similar between analyses, providing additional support for the use of the expectation maximisation approach. Values reported hereafter are unstandardised regression coefficients from analyses with imputation for missing data (except for the physical activity outcome). Among the overall sample, the intervention did not significantly improve MVPA (B [SE] = -1.53 [5.58], P = .78) or percent body fat (B [SE] = -.62 [.39], P = .11). Conversely, the effect of the intervention on muscular fitness approached significance (B [SE] = .18 [.10], P = .07). Among the overweight/obese subgroup, the intervention effect was statistically significant for percent body fat (B [SE] = -1.52 [.56], P = .006) and muscular fitness (B [SE] = 0.27 [.12], P = .03). However, there were also no significant effects for MVPA (B [SE] = -1.5 [8.2], P = .85).

Action theory test (Pathway A)

Significant intervention effects were observed for resistance training skill competency in both the overall sample (B [SE] = 4.6 [.5], P <.001) and among the overweight/obese subgroup (B [SE] = 4.3 [1.0], P <.001).

Conceptual theory tests (Pathway B)

Following adjustment for individual SES, school, group allocation, and baseline values, resistance training skill competency at post-intervention was significantly associated with percent body fat (B [SE] = -.21 [.05], $P < .001$) and muscular fitness (B [SE] = .04 [.02], $P = .02$) among the overall sample. Resistance training skill competency was not significantly associated with MVPA (B [SE] = .10 [.40], $P = .81$) at post-intervention. Among overweight/obese boys, the association with resistance training skills approached significance for percent body fat, but was not significant for muscular fitness or MVPA.

Mediation tests (Pathway AB)

Among the overall sample, the mediated effect was statistically significant for percent body fat (B [SE] = -.95 [.26]; 95% CI = -1.49 to -.47) and muscular fitness (B [SE] = .16 [.07]; 95%CI = .03 to .31). Conversely, the mediated effect was not significant for MVPA (B [SE] = .50 [2.1]; 95%CI = -3.6 to 4.6). Among the overweight/obese subgroup, the mediated effect approached significance for percent body fat, but was not significant for MVPA or muscular fitness.

****Table III near here****

Discussion

The aim of the present study was to examine the potential mediating effects of resistance training skill competency on changes in percent body fat, muscular fitness and physical activity among boys participating in the ATLAS intervention. To the authors' knowledge this is the first study to investigate the link between resistance training movement skills and health outcomes. Resistance training skill competency was found to be a statistically significant mediator of percent body fat and muscular fitness. Conversely, no significant mediated effects were observed for physical activity.

Although school-based health behaviour interventions often target theoretical mediators, analyses of the mechanisms of change in these studies are rarely performed (Lubans, Foster, & Biddle, 2008). Consequently, our current understanding of 'what works' in behavioural interventions is largely based on inference, rather than on empirical evidence. Our findings therefore, address a notable gap in the literature. Due to the novelty of our hypothesised mediator, comparisons with other studies are problematic. However, previous research has found that fundamental movement skill proficiency during youth is related to physical activity, cardiorespiratory fitness, and body composition (Lubans et al., 2010). Additionally, significant associations between motor competence and muscular fitness among children and adolescents have been reported (Haga, 2008; Hands, Larkin, Parker, Straker, & Perry, 2009), albeit in cross-sectional studies. During our initial evaluation of the Resistance Training Skills Battery (Lubans, Smith, Harries, et al., 2014), we found that resistance training skill competency was significantly associated with muscular fitness in a sample of 12-16 year old adolescents, with the overall skill score independently explaining 39% of the variance. However, due to the cross-sectional nature of the study causation could not be determined. The results of the present study extend our previous findings, demonstrating a potential causal relationship between resistance training skill competency and both muscular fitness and body composition in adolescent males.

There are a number of possible explanations for these findings. Firstly, it is likely that improvements in resistance training skill competency enabled more effective exercise performance during the school sport sessions. For example, performing exercises with correct technique and through the full range of motion may have resulted in a greater training stimulus, facilitating larger gains in muscular fitness. Further, although training-induced gains in muscular fitness during early adolescence are partly due to neural adaptations (Lloyd et al., 2013), it is possible that boys with greater skill competency achieved the level of training intensity sufficient to trigger increases in lean mass, which could also explain the mediated effect for body composition. Alternatively, the use of proper exercise technique may have resulted in greater energy expenditure during the school sport sessions, influencing boys' body composition through the effect on energy balance. Secondly, the ATLAS program was designed to satisfy boys' basic psychological need for competence by providing them with opportunities to develop their resistance training movement skills. The Trans-Contextual Model (Hagger, Chatzisarantis, Culverhouse, & Biddle, 2003) posits that autonomous motivation for physical activity in one context (e.g., school sport) can translate into motivation for physical activity in other contexts (e.g., leisure-time). Therefore, in line with the tenets of Self-Determination Theory (Deci & Ryan, 1985), participants may have experienced greater autonomous motivation to engage in resistance training activities during their leisure-time. Finally, it is possible that improvement in resistance training skills was a proxy for program adherence, meaning that improvement in skill competency was simply capturing participation and engagement with the ATLAS program.

As hypothesised, the ATLAS intervention improved boys' resistance training skill competency. The mean improvement in the overall skill score among intervention boys - above and beyond that of the control group - was 4.1 units, corresponding to a moderate effect size ($d = .71$). Although this is the first intervention to assess resistance training skill competency, previous interventions have been successful in improving fundamental movement skills among children (Morgan et al., 2013). Furthermore, a meta-analysis of resistance training studies demonstrated that this training modality is effective for improving sports-related motor skills among children and adolescents (Behringer, vom Heede, Matthews, & Mester, 2011). Unlike improvements in muscular fitness, which will deteriorate quickly upon the cessation of training (Lloyd et al., 2013), a learned movement pattern is more permanent (Gallahue & Ozmun, 2006), and there is emerging evidence that interventions aimed at improving fundamental movement skills result in sustained changes in this outcome (Lai et al., 2014; Morgan et al., 2013). This is in contrast to physical activity and fitness outcomes which may be less stable over time (Lai et al., 2014). Importantly, these data suggest that the basic skills required to be physically active will be retained once they are learned, thereby enabling effective movement performance throughout the lifespan. Considering the potential for resistance training to become a lifelong physical activity, improving competence in related movement skills is a valuable intervention outcome. Learning the requisite movement skills to be successful in this form of activity could remove a considerable barrier to future participation.

Despite significant mediation effects for muscular fitness and body composition, resistance training skills did not appear to be a mediator of physical activity. The conceptual model proposed by Stodden et al. (2008) posits that motor competence influences body composition through health-related fitness and physical activity. However, the null findings for physical activity may be due to the challenges of using accelerometers to measure physical activity in adolescents. As only 36% of boys provided complete data for resistance training skill competency and MVPA, our statistical power was substantially reduced. In addition, although accelerometry is considered a high quality measure of physical activity, these devices are best suited for detecting ambulatory movement (e.g., running). The ATLAS intervention was focused on developing competence in resistance training, which typically involves non-ambulatory movements that may not be detected by accelerometers (e.g., body weight squat). Previous research has shown that providing incentives contingent on the provision of valid data, and keeping a physical activity log are effective strategies for improving compliance with accelerometry among high school-aged students (Sirard & Slater, 2009). Although these strategies were used in the present study, they did not appear to be effective at improving compliance. As evidence for the validity of new monitoring devices (e.g., wrist-worn personal activity trackers) becomes available, researchers should consider using these devices as they may be more acceptable to adolescents and hence may improve participant compliance with monitoring protocols.

Despite statistically significant intervention effects for muscular fitness and percent body fat among overweight/obese boys, no significant mediated effects were observed among this subgroup. Although the threshold for statistical significance was not reached, the mediated effect for percent body fat was in the hypothesised direction and accounted for 49.6% of the intervention effect. Considering that ATLAS targeted a number of weight-related behaviours (i.e., physical activity, screen-time, and sugared beverage intake), it may be that the effect of the intervention on body fat for overweight/obese boys was also due to changes in these behaviours.

The findings of this study have implications for the assessment and evaluation of youth exercise programs. While fitness testing has traditionally been the preferred method for evaluating training progress, we suggest that resistance training movement skill development may be an equally valuable outcome, particularly among novice trainers. This may be of considerable importance considering the influence of maturation on responses to training (Lloyd et al., 2013). Individuals with limited improvement in fitness following an exercise program may remain motivated if they experience tangible improvements in skill competency. Conversely, if success is based solely on fitness outcomes, these individuals may become disheartened and discontinue participation. According to the model proposed by Stodden et al., (2008), youth with low motor competence are likely to become trapped in a continuous cycle of disengagement from physical activity, leading to a future of poor health outcomes. Importantly, resistance training may be a suitable activity for overweight/obese youth who often display low levels of motor competence and struggle physically with the aerobic activities they are typically prescribed (Lloyd et al., 2013). As demonstrated, improving resistance training skill competency is an achievable intervention outcome for overweight/obese youth. However, further research is needed to determine the mediating mechanisms behind changes in fitness and body composition among this subgroup

The strengths of our study include the experimental design, objective assessment of skill competency, and use of robust multi-level mediation techniques. Unfortunately, the limitations associated with physical activity measurement may have hampered our ability to properly examine the association between resistance training skill competency and physical activity. Finally, as the study sample were adolescent males from schools in low-income communities, care should be taken in generalising study findings to other groups.

Conclusions

Previous research has shown that properly designed and supervised resistance training programs are a safe and effective way of improving muscular fitness and decreasing adiposity among young people (Lloyd et al., 2013). However, to date, little research has focused on the role of movement skills in achieving the health outcomes commonly sought from this mode of exercise. To the authors' knowledge, ATLAS is the first intervention to explicitly target resistance training movement skill development in the school setting. Moreover, this is the first study to empirically examine the mediating role of resistance training movement skills for health-related outcomes. This study has identified a feasible and efficacious approach for achieving improvements in body composition and muscular fitness among adolescent males. Future research should explore the contribution of motivational factors in the association between movement skill development and changes in health-related fitness, using Self-Determination

Theory (Deci & Ryan, 1985) as a framework. Furthermore, there is a rationale for investigating skill competency related to other lifelong activities (e.g., Yoga), and their relationships with physiological and psychosocial health outcomes. Finally, replication of these findings in other population groups (i.e., young females) is warranted.

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Table I. Baseline characteristics of study sample

Characteristics	**Control (*n* = 180)**	**ATLAS (*n* = 181)**	**Total (*N* = 361)**
Age, years	12.7 (0.5)	12.7 (0.5)	12.7 (0.5)
Born in Australia	168 (93.3)	174 (96.1)	341 (94.7)
English language spoken at home [a]	169 (94.4)	175 (96.7)	344 (95.6)
Cultural background [b]			
Australian	132 (73.7)	145 (80.6)	277 (77.2)
European	31 (17.3)	22 (12.2)	53 (14.8)
African	6 (3.4)	1 (0.6)	7 (1.9)
Asian	3 (1.7)	4 (2.2)	7 (1.9)
Middle eastern	2 (1.1)	0 (0)	2 (0.6)
Other	5 (2.8)	8 (4.4)	13 (3.6)
Socioeconomic position			
1-2	55 (30.9)	49 (27.1)	104 (29.0)
3-4	81 (45.5)	120 (66.3)	201 (56.0)
5-6	27 (15.2)	4 (2.2)	31 (8.6)
7-8	8 (4.5)	8 (4.4)	16 (4.5)
9-10	7 (3.9)	0 (0)	7 (1.9)
Weight status			
Underweight	5 (2.8)	2 (1.1)	7 (1.9)
Healthy weight	115 (63.9)	110 (60.8)	225 (62.3)
Overweight	38 (21.1)	39 (21.5)	77 (21.3)
Obese	22 (12.2)	30 (16.6)	52 (14.4)

Note. Data for age are presented as mean (SD). All other data are presented as *n* (%).

ATLAS = active teen leaders avoiding screen-time.

[a] one participants did not report language spoken at home.

[b] two participants did not report cultural background.

Table II. Changes in study outcomes

Outcome	Baseline, Mean (SD)	8-month, Mean (SD)	Change, Mean (SD)
Body fat, (%)			
Intervention	20.1 (8.5)	21.5 (7.5)	1.4 (3.7)
Control	22.3 (8.3)	23.7 (8.1)	1.4 (3.4)
Muscular fitness score [a]			
Intervention	.36 (1.85)	.42 (1.69)	.07 (.93)
Control	-.37 (1.64)	-.34 (1.63)	.01 (.72)
MVPA, minutes [b]			
Intervention	67 (18)	63 (20)	-4 (18)
Control	60 (18)	62 (23)	2 (21)
RT skill competency [c]			
Intervention	30.8 (5.7)	38.3 (5.5)	7.5 (5.1)
Control	29.8 (5.9)	33.2 (5.4)	3.4 (5.0)

Note. Values may differ from those reported in the published outcomes paper due to the use of a different method for imputing missing data.

MVPA, moderate-to-vigorous physical activity; RT, resistance training

[a] Sum of standardised values for the hand grip strength and push-up tests

[b] n = 56 intervention group and n = 74 control group participants provided valid accelerometer data at both baseline and post-test

[c] Possible values range from 0 to 56

Table III. Action theory test, conceptual theory test and significance of the mediated effect of resistance training skill competency on study outcomes

Study outcome	Action theory test		Conceptual theory test		Direct effect		Indirect effect	
	A (SE)	*P*	B (SE)	*P*	C' (SE)	*P*	AB (SE)	95% CI
Overall sample								
Body fat (%)	4.6 (0.5)	< 0.001	-0.21 (0.05)	< 0.001	0.34 (0.38)	0.368	-0.95 (0.26)	-1.49 to -0.47
Muscular fitness [a]	-	-	0.04 (0.02)	0.022	0.03 (0.10)	0.722	0.16 (0.07)	0.03 to 0.31
MVPA (mins/d) [b]	-	-	0.10 (0.40)	0.812	-2.30 (5.34)	0.667	0.50 (2.10)	-3.6 to 4.6
Overweight/obese subsample								
Body fat (%)	4.3 (1.0)	< 0.001	-0.15 (0.09)	0.097	-0.68 (0.63)	0.281	-0.67 (0.44)	-1.62 to 0.12
Muscular fitness [a]	-	-	0.01 (0.02)	0.532	0.23 (0.12)	0.050	0.04 (0.07)	-0.10 to 0.19
MVPA (mins/d) [c]	-	-	0.97 (0.69)	0.164	-6.50 (8.56)	0.448	4.23 (3.24)	-1.7 to 11.1

Note. Values reported are unstandardised regression coefficients.

MVPA = moderate-to-vigorous physical activity

[a] Sum of standardised values for the hand grip strength and push-up tests

[b] *n* = 130 participants in the overall sample provided complete data for resistance training skill competency and MVPA

[c] *n* = 43 participants in the overweight/obese subsample provided complete data for resistance training skill competency and MVPA

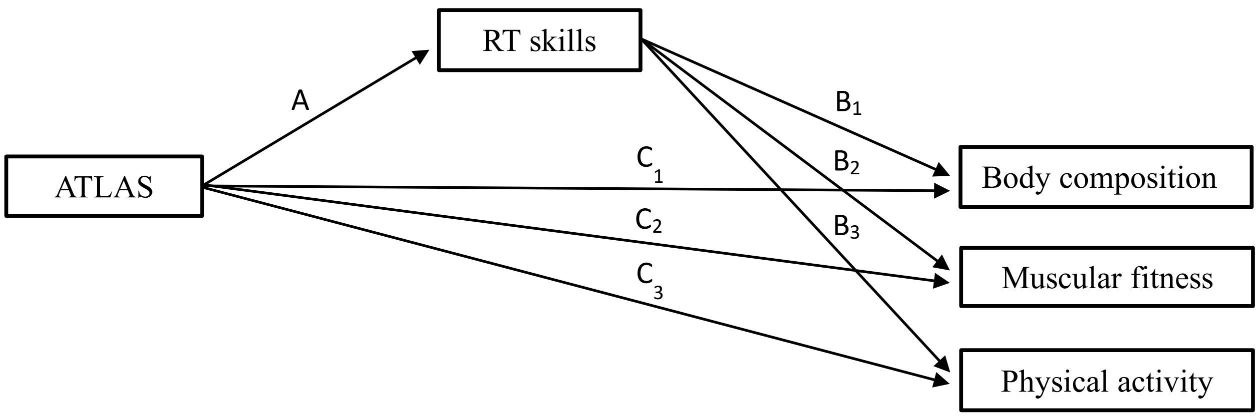

Figure 1. Hypothesised mediation models