



THE UNIVERSITY *of* EDINBURGH

This thesis has been submitted in fulfilment of the requirements for a postgraduate degree (e.g. PhD, MPhil, DClinPsychol) at the University of Edinburgh. Please note the following terms and conditions of use:

This work is protected by copyright and other intellectual property rights, which are retained by the thesis author, unless otherwise stated.

A copy can be downloaded for personal non-commercial research or study, without prior permission or charge.

This thesis cannot be reproduced or quoted extensively from without first obtaining permission in writing from the author.

The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the author.

When referring to this work, full bibliographic details including the author, title, awarding institution and date of the thesis must be given.

The impact of resistance training on correlates of physical activity and physical activity levels in youth.

Helen M Collins

Submitted to the University of Edinburgh as a thesis for the degree of Doctor of
Philosophy

Date: 14/07/21

DECLARATION OF AUTHENTICITY AND AUTHOR'S RIGHTS

*Removed for final version of thesis

ABSTRACT

In youth, there are several benefits of being physically active which are well established. Regular participation has the potential to improve a child's emotional, social and cognitive well-being, as well as physical fitness. Additionally, one of the key identified consequences of not being sufficiently active is the increased chance of obesity, which has significant implications for health. While the UK physical activity (PA) guidelines recommend 'activity to develop movement skills, muscular fitness and bone strength', there has been limited research to date on the impact of resistance training (RT) on health-related outcomes in youth. RT has been suggested to have a positive impact on weight status, fundamental movement skills (FMS) and 'the self', with strength being identified as a possible mechanism underlying these effects. These outcomes are identified as being associated with PA (thus, correlates of PA). Therefore, they may be important mediators of a possible effect of RT on moderate to vigorous physical activity (MVPA).

The overall purpose of this thesis was to therefore explore the impact of RT on strength, correlates of PA, and PA levels in youth. Three systematic reviews and meta-analyses provided a comprehensive literature review on the effect of RT on three identified correlates of PA: weight status, fundamental movement skills (FMS) and 'the self' in youth. These reviews have each been published in *Sports Medicine - Open*. Overall, there was evidence to suggest that RT could have a positive impact on the specified correlates of PA, supporting the hypothesis that there could be a positive effect of RT on PA levels. It was apparent that further research would be beneficial, particularly as there was not an extensive volume of quality research focussed on the impact of isolated RT on the correlates of PA and directly on MVPA. Based on the information obtained through the systematic reviews, two feasibility studies were developed and undertaken that explored recruitment, location, participants, assessment, and intervention design with the aim of informing a pilot study. These studies informed the design of the pilot study which was a quasi-randomly controlled RT pilot intervention in 12, inactive and/or overweight/obese 8-10 year olds. Pre and post intervention assessments for strength, physical self-perceptions (PSPs), weight status, fundamental movement skills (FMS), and PA levels were completed. The exercise group (EG) participated in a 10-week RT

programme twice a week. There were significant time x group interactions for FMS (CAMSA total $P = 0.016$, CAMSA skill score $P = 0.036$) and stretch stature ($P = 0.002$) with the EG displaying larger changes than the CG. Additionally, large effect sizes were evident for CAMSA total score (Hedges' $g = 0.830$, $P = 0.138$), CAMSA skill score (Hedges' $g = 0.895$, $P = 0.112$) and relative strength (Hedges' $g = 0.825$, $P = 0.140$) although these did not reach conventional levels of statistical significance.

This study provided evidence that there are some positive effects of RT on correlates of PA, although unfortunately, there were not sufficient MVPA data to enable any association between RT and PA levels to be investigated in detail. However, this trial enabled the calculation of sample sizes to inform the design of a future definitive RCT. It was evident from the attendance figures and comments from the feedback sessions that a RT intervention was feasible in an inactive and/or overweight/obese youth population, lending support for a larger scale study.

Overall, the thesis provides evidence to support the hypothesis that RT could have a positive impact on strength and the correlates of PA, but it is still unclear whether there is an impact on MVPA. This body of research also demonstrates that RT is a feasible activity for the specified population. The findings of this thesis inform the development of future PA interventions to support children to increase and/or maintain PA participation that includes both strength-based activity and MVPA. This thesis builds on previous work that has explored the topic of RT and the health of youth and introduces the novel concept that there may be a beneficial effect of RT and PA levels.

LAY SUMMARY

Name of student:	Helen Collins	UUN	S1581138
University email:	S1581138@ed.ac.uk		
Degree sought:	PhD	No. of words in the main text of thesis:	50000
Title of thesis:	The impact of resistance training on correlates of physical activity and physical activity levels in youth.		

There is a worldwide physical activity and obesity crisis in children, and because of this, research is crucial to help us understand why this is happening and ultimately, to do something about it.

When we are not active enough, there is not only an increased chance of becoming obese, but also a higher risk of getting diseases such as cancer, diabetes and heart disease, with these diseases becoming more common at a younger age.

To help combat this crisis, there are physical activity guidelines in the UK, written by the Chief Medical Officers, which recommend what types of activities are beneficial and how much we should do for good health. Specifically, children should be taking part in moderate-to-vigorous intensity physical activity (MVPA) for an average of at least 60 minutes per day across the week. Additionally, there should be a variety of types and intensities of physical activity to develop movement skills, muscular fitness, and bone strength. There should also be minimal sedentary time. Unfortunately, not enough children are meeting the MVPA section of the guidelines, and, we don't currently know how many children take part in strength-based exercise despite it being an important component of the guidelines.

One type of strength-based activity is resistance training, and this commonly involves lifting weights. This mode of activity is possibly not as popular as other activities due to the perception that it could be dangerous for children. However, on the contrary, there is research that tells us that, if performed safely and under supervision, there are countless

benefits of resistance training for children, including: improving muscle and bone strength, improving movement skills, helping maintain a healthy body weight and improving self-confidence. A possible benefit that we don't yet know a lot about is whether resistance training could also help children increase their MVPA. This is particularly important, and relevant, for children who are less active or obese and may find other activities difficult.

To look at this in more detail in this thesis, I first reviewed the previous research and found that although there was some evidence of a positive effect of resistance training on physical activity, body fat, movement skills and self-confidence, it was clear that more quality research was needed. The reviews I undertook have been written up and published as three research papers. As a follow on to this, an intervention study was planned. To make sure my study would be robust, I first undertook two feasibility studies to investigate how I would get the children involved, what the resistance training programme would include, and what measurements would be taken to evaluate the programme. This was a beneficial process to help design a 'pilot study' to investigate whether I could encourage inactive/obese children to take part in resistance training and if so, whether this type of training could help to improve strength, movement skills, self-confidence or body fat and whether it could also help the children become more physically active.

After a 10 week period of resistance training, taking part twice a week, the children improved their strength and movement skills, but there was no change to their weight, body fat or self-confidence. Unfortunately, there was not enough data able to be collected on physical activity levels to know if there were any improvements in MVPA, highlighting a challenge of monitoring physical activity levels in this age group. This small study is under review for publication and has provided recommendations for a future, larger scale study to explore this topic in more detail. One very positive outcome was that there was excellent attendance at the training sessions and the children said they enjoyed attending. This seems to be logical, because for inactive/obese children, resistance training could be more fun, and more empowering, than other activities they may feel uncomfortable doing (such as ones that involve running) or may not be as good at.

Overall, the findings from this thesis would suggest that resistance training is a worthy, enjoyable, type of physical activity for inactive/obese children to take part in, and more research is recommended to further support the encouraging preliminary findings that resistance training is both directly and indirectly, beneficial for health.

ACKNOWLEDGEMENTS

Deciding to do a PhD later in life has been challenging in many ways but has been one of the best decisions I have made. I have learnt a huge amount both about the topic, but also about myself, and have thoroughly enjoyed the process (although obviously with many hiccups along the way!).

Firstly, and most importantly, I would like to thank my incredible supervisory team. Audrey, Sam and Josie have guided and supported me much more than I could have hoped for and for that I am hugely grateful. Nothing has ever been too much trouble for them, despite being so busy, and they have helped me to develop confidence in my ability as a researcher throughout the whole process.

I would also like to thank all the members of PAHRC who have shown interest and support throughout my journey, they are a fabulous team. I would like to thank the University of Dundee for appreciating the benefits of providing me with the opportunity to conduct this project as part of my current role.

I would like to thank my family and friends for always being there for me, in particular my husband Rob (who had the fun job of proof reading this thesis) and my daughter Chloe, who arrived mid-way through this process to add an additional challenge!

Finally, I would like to thank the fantastic participants. I never thought I would enjoy coaching children in the way that I have. It has been such a rewarding and fun experience and the children were engaged throughout. Even more importantly, they have continued to take part beyond this project, which was the whole reason for me doing this PhD in the first place... to make a difference.

SUMMARY OF PUBLICATIONS, SUBMITTED MANUSCRIPTS, PRESENTATIONS AND MEDIA LINKS

Publications

- Published paper: **Collins, H.**, Fawkner, S., Booth, JN., Duncan, A. The effect of resistance training interventions on weight status in youth: a meta-analysis. 2018. *Sports Medicine- Open*. 20;4(1):41
- Published paper: **Collins, H.**, Booth, JN., Duncan, A., Fawkner, S. The effect of resistance training interventions on fundamental movement skills in youth: a meta-analysis. 2019. *Sports Medicine- Open*. 17;5(1):17.
- Published paper: **Collins, H.**, Booth, JN., Duncan, A., Fawkner, S., Niven, A. The effect of resistance training interventions on 'the self' in youth: a systematic review and meta-analysis. 2019. *Sports Medicine- Open*. 3;5(1):29
- BASES Expert Statement: Invited author: FBASES, G. S., Foweather, L., **Collins, H.**, & Stodden, D. The BASES Expert Statement on the Importance of Fundamental Movement Skills for Children's Physical Activity and Health. 2020. *h/p/cosmos Gaitway 3D*, 6.

Publications under revision

- **Collins, H.**, Booth, JN., Duncan, A., Fawkner, S. The impact of resistance training on strength and correlates of physical activity in youth. *Journal of Sports Science*. Revisions submitted.

Presentations

BASES Annual Conference. November 2021 (abstract submitted):

ISPAH Annual Conference. October 2021 (abstract submitted): The impact of a resistance training intervention on fundamental movement skills of inactive and/or overweight/obese youth.

ISBNPA Annual Conference. June 2021. Oral presentation: The impact of a resistance training intervention on strength and weight status of overweight/obese and/or inactive youth.

UKSCA Schools SIG. June, 2021. Invited Speaker: Resistance training in youth – combatting physical inactivity to improve health.

SPARC Conference. November, 2020. Invited Speaker: Building strong foundations for an active life.

UKSCA Health and Well-being SIG. September 2020. Invited speaker: Youth S&C: more than sport?

UKSCA Annual Conference. June 2019. Poster: The effect of resistance training interventions on ‘the self’ in youth: a meta-analysis.

Youth Conference. January 2019. Invited Speaker. Building strong foundations for an active life.

BASES Annual Conference. November 2018. Poster: The effect of resistance training on fundamental movement skills in youth: a meta-analysis.

SPARC Conference. November 2018. Poster. The impact of a resistance training intervention on the weight status of overweight children: A case study.

SPEHS Research Cluster presentation. October 2018. Poster: The impact of a resistance training intervention on the weight status of overweight children: A case study.

UKSCA Annual Conference. August 2018. Poster: The impact of a resistance training intervention on the weight status of overweight children: A case study.

SPARC Conference. November 2017. Oral presentation. The effect of resistance training interventions on weight status in youth: a meta-analysis.

Moray House Interweaving Conference. September 2017. Poster: The effect of resistance training interventions on weight status in youth: preliminary findings of a meta-analysis.

UKSCA Annual Conference. August 2017. Poster: The effect of resistance training interventions on weight status in youth: preliminary findings of a meta-analysis.

SPEHS Research Cluster presentation. June 2017. Poster: The effect of resistance training interventions on weight status in youth: preliminary findings of a meta-analysis.

SPARC Conference. November 2016. Poster: The effect of resistance training interventions on weight status in youth: preliminary findings of a meta-analysis.

Media Links

- Arrow Movement Academy Podcast - <https://anchor.fm/jamie-blair49/episodes/Episode-5---Helen-Collins-e139ome>
- Athletic Evolution: Ask the Expert – <https://athleticevolution.co.uk/2019/07/ask-the-expert-helen-collins/>
- Athletic Evolution: Podcast – The benefits of resistance training for children - <https://athleticevolution.co.uk/2020/09/helen-collins-university-of-dundee-the-benefits-of-resistance-training-for-children/>
- Synapse Performance: Podcast – Is resistance training the key for combatting childhood obesity? https://www.youtube.com/watch?v=qzC0xaotU_A
- Publications mentioned in 111 news headlines worldwide.

FIGURES AND TABLES

Chapter 1

Figure 1	Pediatric inactivity Triad (PIT) (with permission from Current Sports Medicine Reports).	20
-----------------	--	----

Chapter 2

Published paper 1 - The effect of resistance training interventions on weight status in youth: a meta-analysis.

Figure 1	PRISMA flow diagram of systematic search and included studies.	3
Table 1	Systematic review categories and search terms	3
Table 2	Description of included studies/data sets	6
Figure 2	Summary of all weight status meta-analyses	11
Figure 3	Funnel plot	12
Table 3	Moderator analysis	13

Published paper 2 - The effect of resistance training interventions on fundamental movement skills in youth: a meta-analysis.

Table 1	Systematic review categories and search terms	3
Figure 1	PRISMA flow diagram of systematic search and included studies.	5
Table 2	Description of included studies/data sets	6
Figure 2	Summary of all fundamental movement skills meta-analyses	10
Figure 3	Funnel plot of publication bias	11
Table 3	Moderator analysis	11

Published paper 3 - The effect of resistance training interventions on 'The self' in youth: A Systematic Review and Meta-analysis.

Figure 1	Adaptation of the Exercise and Self-esteem (EXSEM) model	3
Table 1	Systematic review categories and search terms	3
Figure 2	PRISMA flow diagram of systematic search and included studies.	5
Table 2	Description of included studies/data sets in the meta-analysis	6
Table 3	Studies not included in the cumulative effect size estimates	8

		11
Figure 3	Forest plot of ‘the self’ meta-analyses	9
Figure 4	Funnel plot	11
 Chapter 3		
Table 1	Strength session content (a)	98
Table 2	Strength session content (b)	108
 Chapter 4		
Table 1	Resistance training programme	126
Table 2	Baseline characteristics	128
Table 3	Changes in outcomes for EG and CG pre and post intervention	129
 Chapter 5		
Figure 1	Pediatric inactivity Triad (PIT) (with permission from Current Sports Medicine Reports).	144
Figure 2	Conceptual model of the impact of resistance training on physical activity levels.	145

CONTENTS

DECLARATION OF AUTHENTICITY AND AUTHOR'S RIGHTS	2
ABSTRACT	3
LAY SUMMARY	5
ACKNOWLEDGEMENTS	7
SUMMARY OF PUBLICATIONS, SUBMITTED MANUSCRIPTS, PRESENTATIONS AND MEDIA LINKS	8
FIGURES AND TABLES	10
CHAPTER 1: INTRODUCTION	15
1.1. Physical activity and youth	15
1.2. Youth and physical activity - definitions	16
1.3. Physical activity guidelines and levels	17
1.4. Resistance training in youth	18
1.5. Resistance training and physical activity levels	19
1.6. Correlates of physical activity	21
1.6.1. Weight status	22
1.6.2. Fundamental movement skills (FMS)	24
1.6.3. The self	26
1.7. Barriers to PA participation and the role of RT	27
1.8. Structure of the thesis and purpose of the research	29
CHAPTER 2: SYSTEMATIC REVIEWS AND META-ANALYSES	32
2.1 Introduction to systematic reviews and meta-analyses	32
2.2 The effect of resistance training interventions on weight status in youth: a meta-analysis	33
2.3 The effect of resistance training interventions on fundamental movement skills in youth: a meta-analysis.	50
2.4 The effect of resistance training interventions on 'The Self' in youth: a Systematic Review and Meta-analysis.	67
2.5 Summary of findings	82

	13
2.5.1 Recent research – an update	83
2.5.1.1 Weight status	83
2.5.1.2 Fundamental movement skills	85
2.5.1.3 'The self'	85
CHAPTER 3: FEASIBILITY STUDIES	87
3.1 Part a	87
3.1.1 Introduction	87
3.1.1.1 Published study design	88
3.1.1.1.1 <i>Recruitment strategies used in published studies</i>	88
3.1.1.1.2 <i>Participant details from published studies</i>	88
3.1.1.1.3 <i>Published studies location selection</i>	90
3.1.1.1.4 <i>Assessment selection in published studies</i>	90
3.1.1.1.5 <i>Published studies intervention design</i>	91
3.1.2 Feasibility study aim	92
3.1.3 Methods	92
3.1.3.1 Recruitment	92
3.1.3.2 Participants	93
3.1.3.3 Location	93
3.1.3.4 Assessment	94
3.1.3.4.1 <i>Weight status</i>	94
3.1.3.4.2 <i>Physical self-perceptions</i>	94
3.1.3.4.3 <i>Fundamental movement skills</i>	95
3.1.3.4.4 <i>Strength</i>	95
3.1.3.4.5 <i>Physical activity levels</i>	96
3.1.3.5 Strength session	97
3.1.3.6 Feedback session and questionnaire	98
3.1.4 Results	99
3.1.4.1 Feedback session and questionnaire	99
3.1.4.2 Issues with recruitment	99
3.1.4.3 Participants	99
3.1.4.4 Location	99
3.1.4.5 Assessment	100
3.1.4.6 Strength session	100
3.1.5 Discussion	101
3.1.5.1 Recruitment evaluation	101
3.1.5.2 Participant details	102
3.1.5.3 Location evaluation	102
3.1.5.4 Review of assessments	102
3.1.5.5 Strength session evaluation	104
3.2 Part b	105
3.2.1 Methods	105
3.2.1.1 Recruitment	105
3.2.1.2 Participants	106
3.2.1.3 Assessment	106

	14
3.2.1.4 Intervention content	108
3.2.1.5 Feedback Session	109
3.2.2 Results	109
3.2.2.1 Feedback session details	109
3.2.2.2 Recruitment strategy effectiveness	109
3.2.2.3 Participant details	110
3.2.2.4 Assessment evaluation	110
3.2.2.5 Intervention content	111
3.2.3 Discussion	112
3.2.3.1 Recruitment strategy evaluation	113
3.2.3.2 Participant details	114
3.2.3.3 Location evaluation	115
3.2.3.4 Review of assessments	115
3.2.3.5 Intervention evaluation	116
3.2.4 Conclusion	116
CHAPTER 4: PILOT STUDY	117
CHAPTER 5: DISCUSSION	138
5.1 Research question 1	138
5.1.1 Weight status	139
5.1.2 Fundamental movement skills	140
5.1.3 The self	141
5.2 Research question 2	143
5.3 A working model	143
5.4 Strengths and limitations	146
5.5 Recommendations for future research and practice	148
5.6 Conclusion	149
REFERENCES	150
APPENDICES	166

CHAPTER 1: Introduction

1.1. Physical activity and youth

Physical activity (PA) is widely researched across the world due to its importance for health, with evidence that regular PA helps prevent and treat a range of noncommunicable diseases (NCDs) such as heart disease, stroke, diabetes and breast and colon cancer (1). It also helps to prevent hypertension, obesity, and can improve mental health, quality of life and well-being (1). Specifically, in youth, there are several benefits of being physically active which are well established. Regular participation has the potential to improve a child's emotional, social, and cognitive well-being, as well as health and physical fitness (2). Whilst there is evidence to support the enhanced health benefits of moderate over light intensity PA (3), it has been established that even modest amounts of PA can have health benefits in high-risk young people (e.g. those who are obese) (4).

There is evidence to suggest that PA tracks from childhood to adulthood (5) and an up-to-date review of evidence states that appropriate levels of PA in adulthood reduces the risk of several diseases (e.g. diabetes, cardiovascular disease) and contributes to the development of healthy tissues, a healthy cardiovascular system and neuromuscular awareness (6). Specifically, a recent systematic review has reported that higher vigorous-intensity physical activity (VPA) during childhood seems to be negatively associated with adiposity and cardiometabolic risk score and positively associated with cardiorespiratory fitness and total body bone mineral density later in life (3). Additionally, in adults it has been reported that the risk reduction for those who are highly active is 14% for breast cancer, 21% for colon cancer, 28% for diabetes, 25% for ischemic heart disease and 26% for ischemic stroke (7). Therefore, it is beneficial to promote and support appropriate PA levels in children to ensure a healthy childhood and to reduce the chance of disease later in life.

One of the key identified consequences of not being sufficiently active is the increased chance of obesity, which has significant implications for health (8). Childhood obesity is associated with a higher chance of obesity in adulthood,

premature death and disability (8). In addition to increased future risks, obese children experience breathing difficulties, have an increased risk of fractures, hypertension, early markers of cardiovascular disease, insulin resistance, and experience negative psychological effects (8). The World Health Organisation (WHO) reported that 340 million youth worldwide aged 5-19 were overweight or obese in 2016 (8) and in Scotland in 2019, 16% of children were identified as being at risk of obesity (9). Prevention and treatment programmes suitable for overweight and/or obese youth have been developed in which PA is an integral component (6). Owing to the high risk of overweight youth becoming obese adults, Hills *et al.* reported that the engagement of youth in physical activity and sport is a fundamental component in the prevention of obesity (10).

1.2. Youth and physical activity - definitions

When referring to 'youth' in the context of this thesis, it is important to define what is meant by this term. The United Kingdom Strength and Conditioning Association (UKSCA) position statement on youth resistance training defines the term 'children' as girls and boys (generally up to the age of 11 years and 13 years respectively) who have not developed secondary sex characteristics and the term 'adolescence' refers to a period of life between childhood and adulthood. The term 'youth' represents a global term which includes both children and adolescents (11). Additionally, the UK physical activity guidelines identify children and young people as 5-18 years old (12) so therefore, based on these guidelines and the UKSCA definitions, reference to 'youth' in this thesis includes children and adolescents from the age of 5-18 years.

Despite having already identified the benefits of PA for youth, it is important to define what is meant by PA. Physical activity is defined as "*Any bodily movement produced by skeletal muscles that results in energy expenditure.*" (13 p.26). Metabolic equivalents of activities (metabolic equivalent of tasks, METs) are a ratio of metabolic rate during PA to resting metabolic rate and relate to oxygen consumption and consequently energy expenditure of PA (14). Resting metabolic rate (RMR) refers to the amount of energy consumed under resting conditions and is equal to 1 MET. As intensity of PA increases, oxygen consumption and energy expenditure increase and the MET value in multiples of RMR rises. Moderate intensity PA

equates to approximately 3-6 METs (3-6 times greater energy expenditure than when at rest) (14). An example of an activity performed at this intensity would be brisk walking. Vigorous intensity PA is >6 METs (14) and an example of this would be jogging/running. As it is evident that being physically active is beneficial for the health of youth, it is essential to distinguish how much activity is required and what kind of activities are favourable to gain the benefits. Therefore, guidelines have been developed and implemented to address this issue.

1.3. Physical activity guidelines and levels

The current UK PA guidelines for youth aged 5-18 recommend moderate-to-vigorous intensity physical activity (MVPA) for an average of at least 60 minutes per day across the week (12). Additionally, there should be a variety of types and intensities of PA to develop movement skills, muscular fitness, and bone strength (12). There should also be minimal sedentary time (12). However, despite these guidelines, one of the more recent global surveillance studies, the Health Behaviour in School-aged Children survey (HBSC), reported that across Europe and North America, less than 50% of young people were meeting the recommended levels of MVPA, although it should be noted that sufficient PA was identified as 60 minutes of MVPA daily rather than on average (15). PA levels also demonstrate a decline with age, with 25% of 11 year olds meeting the MVPA recommendations, compared to just 16% of 15 year olds (15). Although this is self-report data, it indicates that as children advance through adolescence, physical inactivity (that is, not meeting the recommended average 60 minutes of daily MVPA) becomes increasingly present. In fact, having levels of MVPA inconsistent with the current public health recommendations has been termed 'Exercise Deficit Disorder' (EDD) (2), which has been proposed as a term to highlight the gravity of this clinical condition, rather than youth just being labelled as 'inactive' (16). In exploring inactivity, the HBSC data reports MVPA, but with the guidelines also including strength and movement skill activities, there is arguably more to understanding PA behaviour than levels of MVPA.

Investigating the level and context of PA, report cards including PA grades of youth have been implemented across 49 countries as a global matrix with grades being awarded for different components of physical activity (with an A grade being the

highest and F being the lowest) (17). This included reporting on 10 common indicators: overall PA, organised sport and PA, active play, active transportation, sedentary behaviours, physical fitness, family and peers, school, community and environment, and government. To investigate whether children are taking part in sufficient activity to develop movement skills, muscular fitness and bone strength, the 'physical fitness' category is based on European normative values for physical fitness in youth aged 9-17, which includes measures of strength (hand grip, sit ups and bent arm hang) (18). However, this category also includes measures that are not strength-based such as a flexibility measure and shuttle run test, so participation in strength-based activity is not reported per se, although strength and movement skills are an important part of the guidelines. Indeed, Faigenbaum *et al.* stated that low levels of muscular strength and power (dynapenia) negatively impact physical, psychosocial, emotional, and behavioural factors that drive physical inactivity in youth (19). Therefore, this suggests that strength-based exercise or 'resistance training' is an integral part of PA for youth, although there is currently no published information regarding youth engagement with the guidelines.

1.4. Resistance training in youth

Resistance training (RT) in youth is becoming a more widely researched area. Firstly, it is important to define what is meant by this term. *"Resistance training (also called strength training) refers to a specialised method of conditioning whereby an individual is working against a wide range of resistive loads in order to enhance health, fitness and performance"* (11 p.1). The National Strength and Conditioning Association (NSCA), the UKSCA and the British Association of Sport and Exercise Sciences (BASES) have developed position statements which emphasise the benefit of youth engagement in RT (11, 20, 21).

As well as defining youth as children and adolescents from the age of 5-18 years (section 1.2), it is important to acknowledge biological maturation, particularly in relation to RT. It is evident that individuals with the same chronological age can differ regarding biological maturity (22) which has implications for training programme design for youth. The 'long-term athlete development model' identifies 'windows of opportunity' where certain physical qualities are more susceptible to training, using

peak height velocity (PHV) as a reference point (23). In particular, the model determines that the time period after PHV is key for strength development due to accelerated growth (23), although it has been reported that this suggestion is not substantially evidence based (24). In a more recent, alternative model, the 'youth physical development model' demonstrates that most, if not all, physical qualities are trainable throughout childhood (25). Specifically for strength, there is evidence which suggests that strength development does not appear to be associated with accelerated growth around puberty, although there may be an increased responsiveness to training with advancing maturational status (26). Overall, it has been suggested that strength development is of equal importance across childhood due to being multifaceted, being the result of a number of factors, including not only an increase in muscle mass, but mechanical and neuromuscular developments, particularly in pre-pubertal children (25).

In fact, research indicates that appropriately designed, and well supervised RT programmes can benefit youth of all ages, with children as young as 5 years of age making noticeable improvements in strength (27). Additionally, RT has numerous health benefits for youth and an appropriate programme has been shown to improve bone health (28), decrease cardiovascular disease risk (20), decrease metabolic risk factors, improve body composition (29) and improve self-esteem (30). Motor skills (such as jumping, running, throwing) have been shown to be improved in youths after a period of resistance training (20). The importance of RT as a mode of PA is clear due the associated health benefits and its inclusion in the PA guidelines. An additional advantage of RT could be a positive impact on MVPA, which is further supported by the 'Pediatric Inactivity Triad' (PIT) (16).

1.5. Resistance training and physical activity levels

The Pediatric Inactivity Triad (PIT, Figure 1) is a condition seen in physically inactive youth involving three separate but inter-related components: 1) exercise deficit disorder (EDD), 2) paediatric dynapenia, and 3) physical illiteracy (see Figure 1)(16). This conceptual model proposes that these three elements interact and ultimately, through interventions designed to have a positive impact on these components, there is the increased likelihood of maintaining a healthy level of PA into adulthood.

EDD as previously mentioned is a condition where levels of MVPA are below recommendations consistent with positive health outcomes (<60 minutes of MVPA daily) (31). Paediatric dynapenia is defined as *“low levels of muscular strength and power not caused by neurologic or muscular disease.”* (16 p. 46) and physical illiteracy is defined as *“the lack of confidence, competence, motivation, and knowledge to move proficiently in a variety of physical activities.”* (16 p. 46). These latter two components are interrelated and treatable conditions which both affect and are affected by EDD (16). This is important because many interventions are focussed on increasing MVPA but this might not be sustainable or have as much impact without consideration for the other two parts of the triad. For example, walking programmes that attempt to increase MVPA in youth overlook the critical importance of enhancing neuromuscular fitness and improving physical literacy (16). Therefore, the suggestion is that by delivering interventions that include activities that improve strength, movement competence and confidence (e.g. RT) this could be an effective strategy to improve PA levels.

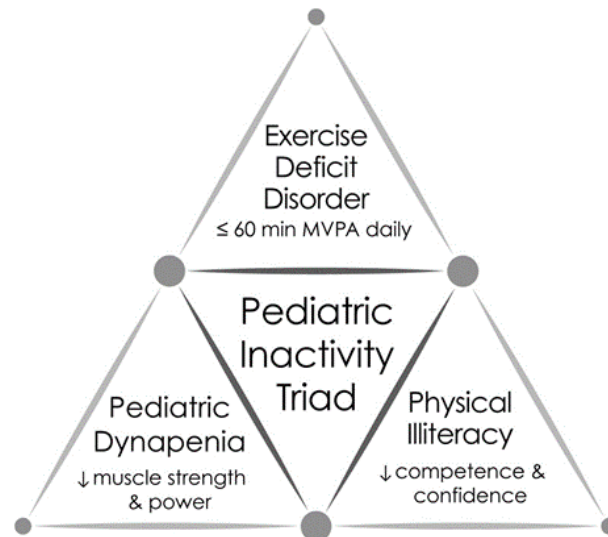


Figure 1- Pediatric Inactivity Triad (PIT)(16) (with permission from Current Sports Medicine Reports).

There are only two studies found to date that have investigated the direct effect of RT on PA levels in youth. They found significant increases in daily spontaneous PA in 10-14 year olds following a RT intervention (32, 33). Meinhardt *et al.* included 102

children (42 girls and 60 boys) who took part in a school-based resistance training programme two to three times a week for 19 weeks with the sessions being 45 minutes in duration (32). There was a significant increase in daily spontaneous PA in the boys but not the girls. However, the age range spanned across different pubertal stages with most of the girls being pubertal in contrast to the boys who were mainly prepubertal, which may explain the difference in findings between sexes (32). It was also unclear whether the children were sufficiently active prior to the study, and it was not apparent if there were significant differences in PA between the boys and girls at baseline (32). In Eiholzer *et al.* 46 boys participated in a study from two local ice hockey teams which involved taking part in an hour of supervised resistance training, twice a week for 12 weeks. They found a significant increase in the experimental group's PA levels, compared to the control group, despite both groups being competitive ice hockey players (although it was not clear how often they trained per week). Whilst promising, these studies only demonstrated significant findings in males and did not explore the potential underlying mechanisms of the effect, although in both studies there were significant increases in strength. However, in the Meinhardt *et al.* study, increases in strength were identified in both the boys and girls, despite the girls not showing a significant increase in PA (32, 33). Overall, these studies concluded that RT could be used as a strategy to increase PA levels, but further investigation was proposed to substantiate this effect, particularly in inactive individuals and females.

1.6. Correlates of physical activity

Although these two studies provide some evidence to support the association between RT and PA levels, there is no current research that supports possible mediators of this association. There are, however, several factors that have been recognised as being related to PA participation (correlates of PA) and subsequently some of these are associated with RT, identifying them as potential mediators.

Correlates of PA have been categorised as: demographic and biological, (e.g. gender and ethnicity, socio-economic status and BMI), psychological (e.g. perceived competence, self-efficacy and enjoyment), behavioural (e.g. diet and smoking), social/cultural (such as parental support) and environmental (e.g. facilities) (34). It is

important to consider these correlates during intervention design and to evaluate an intervention. However, there are also certain correlates that could be impacted specifically by RT (weight status, fundamental movement skills and 'the self') and could be considered key outcome measures when evaluating the impact of a RT intervention in particular.

RT has been shown to have a positive impact on weight status, fundamental movement skills (FMS) and 'the self' (11) and these outcomes are identified as being associated with PA (thus, correlates of PA) and may be important mediators of a possible effect of RT on MVPA. Additionally, as RT has been found to increase strength in youth, it may be proposed that increases in strength could be an underlying mechanism that could explain a positive effect of RT on the correlates of PA. Therefore, a more in-depth discussion of these correlates and their association with RT is required.

1.6.1. Weight status

'Weight status' is a term used to classify weight categories: healthy, overweight, and obese. Body mass index (BMI) is a simple index of weight-for-height that is commonly used to classify overweight and obesity in adults and is defined as a person's weight in kilograms divided by the square of height in metres (kg/m^2)(8). In youth, BMI Z-scores (standard deviation score), are measures of relative weight adjusted for child age and sex (35). In the UK, BMI Z-scores are commonly calculated using the Cole LMS method and UK 1990 reference data, based on 37,700 children, with an age range of 23 weeks gestation to 23 years (36). Weight status is classified as: healthy weight as BMI Z-score <1.04 ; overweight as BMI Z-score $1.04-1.63$; obesity as BMI Z-score ≥ 1.64 (37).

Additional to BMI, numerous assessment tools have been reported in the literature to measure various outcomes related to weight status in youth. Smith *et al.*, (38) investigated the health benefits of muscular fitness in children and as well as BMI, they also measured skinfolds and waist circumference to provide a comprehensive measure of adiposity. Furthermore, when investigating interventions, studies have looked at changes in body composition, which have been measured using DEXA

scanning (39), MRI scans (40), bioelectrical impedance (41) and skinfolds (42). In the context of this thesis, weight status is identified as an umbrella term that encompasses these measures, and there is a wealth of research that utilises these methods to investigate weight status in the context of PA and RT.

To investigate the association between weight status and PA, Strong *et al.* reviewed cross-sectional and longitudinal observational studies and concluded that youth of both sexes who participate in relatively high levels of physical activity have less adiposity than inactive youth (43). More recent studies have reported associations between weight status and PA (44-46). Fairclough *et al.* obtained data from 409 children and found that weight status of 10-11 year old children was significantly associated with time spent in vigorous physical activity (VPA) (44) with those displaying a healthier weight status taking part in more VPA. Similarly, Ferrari *et al.*, reported MVPA (in boys), and VPA (in boys and girls), are associated with body composition (46). Additionally, Kreuser *et al.* showed strong evidence that overweight children spend more time sedentary and accumulate significantly lower levels of physical activity than their non-overweight counterparts (45). Supporting these studies, Faigenbaum stated that youth who are overweight/obese engage in less MVPA than non-overweight peers (2). There is thus a significant amount of evidence supporting the positive association between weight status and PA and since, as previously mentioned, there is a high risk of overweight adolescents becoming obese adults, Hills *et al.* reported that the engagement of youth in PA is a fundamental in the prevention of obesity (10).

There is a rationale for considering RT as a specific strategy to treat and/or prevent obesity, with an increase in skeletal mass resulting in an increase in basal metabolic rate (38). Systematic reviews have explored the impact of RT on weight status (47-51). However, when examining studies that have included RT alone as an intervention involving overweight/obese children, there are very few studies, a lack of randomised control trials, low sample sizes and inconclusive results (47, 48, 51). Schranz *et al.* reported that interventions that included a RT component had a very small to small effect on body composition in overweight and obese youth and moderate to large effects on strength, however, across studies, there was large variation in intervention content and assessment methods (49). This was supported

by a more recent review specifically investigating the impact of RT on obese, sedentary adolescents (51). The conclusion was that although there was limited evidence, it was suggested that RT alone is associated with a significant increase in muscular strength and reductions in total fat, with no change in weight (51). There has been one systematic review to date with emphasis on the impact of RT on the weight status of both healthy weight and overweight/obese youth (50). Similar to the other reviews, Benson *et al.* identified that due to limitations in methodologies it was difficult to reach conclusions about the isolated role of RT (50). Since the focus of the published reviews has been on obese and overweight youth, or on multicomponent interventions, the isolated role of RT on weight status in youth is not currently known and will be explored in this thesis.

1.6.2. Fundamental movement skills (FMS)

An added complication for overweight/obese children with regards to PA is that they may have greater difficulty performing fundamental movement skills (FMS) (52). There are many terms used in the literature to describe fundamental movement skills, such as motor coordination, motor competency and physical literacy. 'Fundamental movement skills' (FMS) is a term that incorporates activities that require motor coordination. They are an organised series of basic movements that involve a combination of movement patterns of two or more body segments (52). FMS are commonly categorised as: locomotor (e.g. running, jumping, hopping), stability (e.g. balancing, twisting) and object control (throwing, catching, kicking) (52).

Measurement of individual FMS have been used in several 'performance based' studies, such as jump height and sprint speed (53). These are classified as product-oriented measures. Furthermore, various FMS process-oriented instruments have also been utilised, such as the Movement Assessment Battery for Children 2 (54) the Bruininks-Oseretsky Test for Motor Proficiency 2 (55), and the Test of Gross Motor Development 2 and 3 (56, 57). Some of these instruments focus on identifying children with fundamental movement skill development disorders rather than to assess improvements in FMS. Logan *et al.* identified that although process-oriented measures assess the quality of movements performed during skill execution, which is a key component of evaluating FMS, the use of both process- and product-

oriented assessments may provide a more comprehensive view of fundamental motor skill competence (58).

In exploring this relationship between FMS and PA, a systematic review by Holfelder & Schott reported a strong relationship between FMS and organised PA (59). Furthermore, reviewing studies that used process-oriented assessments only, Logan *et al.* reported low to high relationships between FMS competence and PA in middle to late childhood and low to moderate relationships in adolescence (60). Overall, it has been suggested that children who do not enhance their ability to move with competence and confidence in early life are less likely to develop motor skills and perceived confidence to meet the PA recommendations (61). This is supported by the Pediatric Inactivity Triad (PIT) (Figure 1) (16).

The PIT model also alludes to an association between muscular strength and FMS (16) and there have been systematic reviews and meta-analyses conducted on the impact of RT on FMS (62-64). It has been identified that muscular strength is an essential component of motor skill development (65) and both functional (e.g., changes in motor unit coordination) and structural (e.g., muscular hypertrophy) adaptations as a result of resistance training might bring about changes in motor competency (62) which therefore may be linked to the development of FMS. Harries *et al.* (63) conducted a systematic review and meta-analysis which provided evidence for the role of RT in improving indicators of FMS via the assessment of product-oriented assessments (vertical jump and sprint). However, all of the participants in the studies included in the Harries review were athletic adolescents, so this does not provide information regarding younger children, or the possible role of resistance training in those who do not take part in organised sport.

There have also been two meta-analyses to date that have investigated the impact of resistance training specifically on athletic performance, in the form of motor skills (running, jumping and throwing) in both children and adolescents (62, 64). It was shown in both reviews that younger children and non-athletes demonstrated higher gains than athletic children. Supporting these findings, Lesinski *et al.* (64) concluded that resistance training was effective for improving proxies of physical performance in youth athletes, including strength, but with the caveat that most studies were at

high risk of bias (64). In the context of health, there is currently limited research on the isolated impact of resistance training interventions on FMS in non-athletic youth and in particular limited resistance training studies including process-oriented measures. Therefore, a current literature review would be beneficial to investigate this further.

1.6.3. The self

There are psychological outcomes that are associated with PA that are worthy of investigation, with a key outcome being identified as ‘the self’ (66, 67). The term ‘the self’ is used in this thesis to capture a range of specific terms that, while separate, are related (e.g. self-esteem, self-efficacy, self-perceptions). In this respect, PA researchers have typically defined ‘the self’ as having a multi-dimensional and hierarchical structure, identified in a model proposed by Fox & Corbin (68). This involves more stable constructs (e.g. self-concept ‘a person’s perception of him or herself’ (69) and self-esteem ‘how an individual feels about their sense of self’ (70)) at the apex of the structure. These are influenced by less stable sub-domains (e.g. physical self-perceptions ‘a person’s perceptions of their physical self’ (71)) and further sub areas (e.g. perceived strength).

A range of questionnaires have been used to measure different parameters of ‘the self’ in PA related studies with youth, such as: The Harter Global Self-Esteem sub-scale (72), Exercise Self-efficacy (73) and Training Self-efficacy and Outcome Expectancy Questionnaire (41). Arguably the most commonly used tool is the Children and Youth Physical Self-perception Profile (CY-PSPP) which has been validated as a method of assessing physical self-perceptions in children and youth (74). Assessing ‘the self’ is feasible in a youth population due to valid tools, and similarly to weight status and FMS research, there are studies that use various tools to investigate associations between various components of ‘the self’ and PA providing rationale for it to be referred to as an umbrella term in this thesis.

There is review level evidence that provides support for a positive relationship between PA and constructs relating to ‘the self’ in youth (66, 67, 75, 76). Babic *et al.* (76) included 64 studies in a meta-analysis and found a significant association

between physical activity and physical self-concept and its various sub-domains in children and adolescents. Despite some limitations regarding methodological design, collectively these reviews provide convincing evidence of the beneficial effects of PA on 'the self'. Further exploring the association between PA and 'the self', Ekeland *et al.* conducted a review to investigate if PA could improve self-esteem in youth. They concluded that although the review included a small amount of low quality trials, there may be short term beneficial effects (75). Supporting these findings in a more recent review, Liu *et al.* conducted a meta-analysis that included twenty-five randomised controlled trial (RCT) studies. Significant positive effects were found for intervention of physical activity alone on 'the self' outcomes concluding that an intervention of PA activity alone is associated with increased self-concept and self-worth in children and adolescents (67). Overall, there is therefore evidence to suggest that 'the self' is associated with PA in youth.

The reviews by Ahn and Fedewa (66) and Liu *et al.* (67) which examined the effect of PA on 'the self' in youth, included RT interventions. However, the independent role of RT was not considered. Indirect support for the independent positive effect of RT interventions on the self therefore currently comes from studies that demonstrate a positive association between muscular fitness and physical self-perceptions (38). Specifically, Lubans *et al.* (77) reported evidence of an association between muscular fitness and physical self-perceptions (perceived physical performance and perceived sports competence), overall physical self-worth and global self-esteem in youth. However, due to the cross-sectional nature of these data, it remains difficult to untangle the direction of the effect. Thus, although there is evidence of an association between muscular fitness and 'the self', it remains unclear whether there is a direct effect of RT on 'the self' and this therefore warrants further investigation.

1.7. Barriers to PA participation and the role of RT

Investigating the correlates of PA that could be identified as mediators of an association between RT and PA is fundamental to inform the development of an effective intervention. Furthermore, it is important to consider correlates of PA and additional factors, as possible barriers to participation. This then enables the implementation of strategies to overcome these barriers.

Allender *et al.* (78) identified barriers to PA participation for children including: competitiveness, peer pressure and negative school experiences. Additionally, Dobbins *et al.* (79) reported barriers including: ridicule of unfit or overweight children during vigorous activity, changing of clothes, and lack of fun for school-based interventions. The nature of RT is not competitive (i.e. it is not sport) and if it is offered as an extra-curricular activity, it should not elicit peer pressure or be associated with negative school experiences. Furthermore, a RT intervention is not necessarily vigorous and therefore may not require changing of clothes. Finally, an intervention should be designed to be enjoyable and fun for the participants. In summary, for the most part, the barriers identified are related to physical education, sport and more aerobic based activities and therefore including RT as an alternative might alleviate some of these issues.

Although there are identified barriers to PA participation, it is also important to consider any factors that may also influence youth participation specifically in RT. A key consideration is parental support, with possible negative perceptions regarding RT for youth (80). In exploring parent's attitudes to strength exercise in comparison to aerobic exercise, Ten Hoor *et al.*, reported that parents display a positive attitude towards aerobic exercises, but a less positive attitude regarding strength exercises (80). Specifically, out of 314 parents, 29.6% indicated that their child was not allowed to participate in strength exercises in comparison to just 4% for participation in aerobic exercises, stating that they thought that strength exercises could hinder optimal physical development (80). This would suggest that for recruitment regarding RT interventions, parents have a crucial role, and therefore facilitating an understanding of the benefits of RT for youth is fundamental. As an additional point, considering the environment, it was also reported that parents may not be aware of appropriate facilities available for RT delivery in comparison to aerobic or sport activities (80). Therefore, providing information regarding possibilities for children would help to negate this issue.

There is evidence to suggest that RT could be an appealing and enjoyable activity for youth, which implies it could be a sustainable and valuable mode of PA. In particular, Ten-Hoor *et al.* suggested that overweight and obese youngsters are

better in (absolute) strength exercises when compared with healthy weight youngsters and strength exercises are easier for them (81). Furthermore, youth have reported that it is fun to engage in strength exercises (81). In further support of the appeal of RT for youth, Pescud *et al.*, interviewed overweight children and their parents regarding factors that may influence commencement and continuation of RT (82). Some of the reasons reported by the parents regarding why they would like their child to be involved in a RT programme included: a desire for their child to lose weight and gain confidence, the proximity of the venue, and no cost for participation. The children reported that they wanted the opportunity to build strength and improve fitness (82). For reasons to continue on the programme, the parents identified the child's improved weight status, coordination, and confidence (82), which provides additional support to focus on the three identified correlates in this thesis.

1.8. Structure of the thesis and purpose of the research

There is evidence to hypothesise that there is a positive effect of RT on MVPA in youth with this effect being mediated by weight status, FMS and 'the self'. However, this requires further investigation. Additionally, strength could be identified as a possible mechanism underlying this effect. The present thesis presents a body of work which investigates this topic through addressing the following research questions;

1. *Does resistance training have an impact on weight status, fundamental movement skills and the self in youth?*
2. *Does resistance training have an impact on physical activity levels (MVPA) in youth?*

Although not initially presented as an overarching research question, it is important to note that strength was included as an additional outcome of interest. This was due to strength being identified as a possible mechanism underlying a direct effect of RT on MVPA and/or on the effect of RT on the identified correlates of PA.

The overall purpose of this thesis was to explore the impact of resistance training on strength, correlates of physical activity and physical activity levels in youth. This

thesis builds on previous work that has explored the topic of RT and the health of youth and introduces the novel concept that there is an association between RT and PA levels.

Chapter 2 includes three systematic reviews and meta-analyses (part a, b and c) and a summary of the overall findings. Although there is review level evidence to support the effect of resistance training on specified correlates of PA, some of this is now more than a decade old. Furthermore, there is limited review level evidence that explores the impact of RT alone on these identified correlates. Therefore, a systematic review and meta-analysis on the effect of RT on each correlate was employed to identify where knowledge was lacking and also support the development of an intervention. Meta-analyses ensured a rigorous process and also provided assessment of the magnitude of effects, in possibly conflicting research findings.

Part a includes the findings of a systematic review and meta-analysis exploring the effect of resistance training interventions on weight status in youth. This has been published in its current format in *Sports Medicine – Open* (83). This paper adds to previous systematic reviews by including both healthy weight and overweight/obese youths thus exploring not only the treatment of obesity but also the prevention, which is a vital component in combatting rising levels of obesity in children. This review also only includes isolated resistance training interventions.

The purpose of the second review (part b, Chapter 2) was to systematically review the literature exploring the effect of resistance training on fundamental movement skills (FMS) in youth. This paper has been published in its current format in *Sports Medicine – Open* (84). This paper was the first review to synthesise research on the effects of isolated RT interventions on FMS.

Part c (Chapter 2) provides the findings of a systematic review and meta-analysis exploring the effect of resistance training interventions on ‘the self’ in youth. This has been published in its current format in *Sports Medicine – Open* (85). This paper was the first review to synthesise research on the effects of isolated RT interventions on

‘the self’. Together, these reviews helped to inform the development of a RT intervention for youth.

Following these reviews, the process of designing an intervention study began. Chapter 3 details two feasibility studies undertaken to explore recruitment, location, participants, assessment, and intervention design. The rationale of the feasibility studies was to inform a pilot study to investigate the impact of RT on correlates of PA and PA levels, which is included in Chapter 4. Chapter 5 is the final chapter providing an overall summary of the key findings, the strengths and limitations of the thesis and implications for future research and practice.

CHAPTER 2: Systematic reviews and meta-analyses

2.1 Introduction to systematic reviews and meta-analyses

To rationalise conducting a systematic review and meta-analysis, according to Gopalakrishnan *et al.* a well conducted systematic review can provide reliable information regarding the effects of an intervention so that there are strong conclusions and a demonstration of where knowledge is lacking, which can then be used to guide future research (86). Additionally, the rationale of a meta-analysis is to summarise data from multiple resources helping to plan research and frame guidelines (86). It is also beneficial in making efficient use of existing data, explaining data inconsistency, and quantifies the data (86). Therefore, it was logical to conduct a systematic review and meta-analysis including studies that explored the effect of RT and the correlates of PA to enable a deeper understanding of the current literature and to develop a robust study design for a pilot study based on the MRC framework for developing complex interventions (87). As previously mentioned, there is limited review level evidence that explores the impact of RT alone on the correlates of PA and some of this is more than a decade old.

The reviews aimed to address three specific research questions:

1. *Do resistance training interventions have an effect on weight status in youth?*
2. *Do resistance training interventions have an effect on fundamental movement skills, in youth?*
3. *Do resistance training interventions have an effect on 'the self' in youth?*

2.2 The effect of resistance training interventions on weight status in youth: a meta-analysis

SYSTEMATIC REVIEW

Open Access



The effect of resistance training interventions on weight status in youth: a meta-analysis

Helen Collins^{1,2*}, Samantha Fawcner², Josephine N. Booth³ and Audrey Duncan¹

Abstract

Background: There has been a rise in research into obesity prevention and treatment programmes in youth, including the effectiveness of resistance-based exercise. The purpose of this meta-analysis was to examine the effect of resistance training interventions on weight status in youth.

Methods: Meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and was registered on PROSPERO (registration number CRD42016038365). Eligible studies were from English language peer-reviewed published articles. Searches were conducted in seven databases between May 2016 and June 2017. Studies were included that examined the effect of resistance training on weight status in youth, with participants of school age (5–18 years).

Results: There were 24 complete sets of data from 18 controlled trials (CTs) which explored 8 outcomes related to weight status. Significant, small effect sizes were identified for body fat% (Hedges' $g = 0.215$, 95% CI 0.059 to 0.371, $P = 0.007$) and skinfolds (Hedges' $g = 0.274$, 95% CI 0.066 to 0.483, $P = 0.01$). Effect sizes were not significant for: body mass (Hedges' $g = 0.043$, 95% CI -0.103 to 0.189 , $P = 0.564$), body mass index (Hedges' $g = 0.024$, 95% CI -0.205 to 0.253 , $P = 0.838$), fat-free mass (Hedges' $g = 0.073$, 95% CI -0.169 to 0.316 , $P = 0.554$), fat mass (Hedges' $g = 0.180$, 95% CI -0.090 to 0.451 , $P = 0.192$), lean mass (Hedges' $g = 0.089$, 95% CI -0.122 to 0.301 , $P = 0.408$) or waist circumference (Hedges' $g = 0.209$, 95% CI -0.075 to 0.494 , $P = 0.149$).

Conclusions: The results of this meta-analysis suggest that an isolated resistance training intervention may have an effect on weight status in youth. Overall, more quality research should be undertaken to investigate the impact of resistance training in youth as it could have a role to play in the treatment and prevention of obesity.

Keywords: Resistance-training, Children, Adolescents, Obesity, Strength, Weight

Key points

- Physical activity guidelines and position statements emphasise the importance of 'activity to strengthen muscle and bone' and research suggests that resistance training might have an impact on weight status in youth.

- This meta-analysis found that resistance training has a positive effect on body fat percentage and skinfolds in youth.
- Further research is required to investigate the role resistance training may play in the treatment and prevention of obesity.

Background

Obesity is a worldwide concern. In 2016, more than 1.9 billion adults were classified as overweight, 13% were obese and 41 million children aged under 5 were overweight or obese [1]. Childhood obesity is a critical public health threat as the prevalence of obesity amongst youth continues to increase worldwide, and there is the risk of

* Correspondence: h.m.collins@dundee.ac.uk

¹Institute of Sport and Exercise, University of Dundee, Old Hawkhill, Dundee DD14HN, UK

²Physical Activity and Health Research Centre, University of Edinburgh, Edinburgh, UK

Full list of author information is available at the end of the article

developing obesity-related diseases at an increasingly younger age [2]. Prevention and treatment programmes suitable for youth have been developed for which physical activity is an integral component [3].

The current guidelines for children aged 5–18 recommend 60 min of daily physical activity (PA), and minimising the time spent sitting each day. They also recommend activity that strengthens muscle and bone, at least 3 days a week [3, 4]. However, despite these guidelines, one of the more recent global surveillance studies, the Health Behaviour in School-aged Children survey [5], reported that across Europe, less than 50% of young people were meeting the current PA guidelines. Additionally, the survey demonstrated a decline in PA levels with age; 25% of 11 years olds met the recommendations, compared to just 16% of 15 year olds [5] which indicates that as children advance to adolescence, sedentary behaviour becomes more common.

A growing volume of studies have now been published that seek to examine the effectiveness of PA interventions designed to combat these low levels [6]. However, in a systematic review of 57 studies that investigated PA interventions in children and adolescents, very few studies that were included examined interventions which addressed compliance with the muscle and bone component of the guidelines [6].

The benefits of resistance training (RT) in youth are well documented, and key organisations (NSCA, UKSCA and BASES) have developed position statements in support of this [7–9]. A benefit identified in these position statements is the positive effect of RT on weight status, although the evidence to support these statements is not strong. In fact, the majority of research investigates multi-component interventions with a focus on overweight/obese youths [10–12].

A systematic review in 2011 identified that very few randomised control trials have examined the effects of RT alone on body composition in overweight or obese adolescents [10]. From just seven studies included in this review that focused on RT alone, the authors reported inconclusive results and the recommendation was for more studies to be conducted that concentrate solely on RT interventions [10]. Also examining the effect of RT alone on overweight or obese children, a further review found only six studies met the inclusion criteria [11]. Three out of the six studies showed a significant decrease in percentage fat and a significant increase in fat free mass, although none of the studies found a decrease in total fat mass. Additionally, all studies reported an increase in body weight. Again, the findings were inconclusive, but they identified there was a lack of randomised control trials (only two studies) and the studies had low sample sizes [11]. In a systematic review and meta-analysis, it was found that interventions that included a RT component had a very small to small effect

on body composition in overweight and obese youth [12]. Studies that included interventions that were RT alone showed similar effects to those studies that included resistance plus an aerobic or dietary component. However, across studies, there was large variation in intervention content and assessment methods [12].

The studies included in these reviews involved only overweight and obese participants and therefore it could be argued that they are focused on the treatment of obesity rather than prevention. However, it has been suggested that early prevention holds better than treatment with ‘primordial prevention’ being the first of three levels of obesity prevention [13]. This emphasises the prevention of risk factors to maintain a healthy weight throughout childhood and into the teens [13].

There has been one systematic review to date with emphasis on the impact of RT on the weight status of both healthy weight and overweight/obese youth [14]. This review included studies using a variety of assessment tools and also studies that combined aerobic training and dietary interventions, however, there were still only 12 studies included in total. Investigating the impact of RT on body composition, they identified that due to limitations in methodologies it was difficult to reach conclusions about the isolated role of RT [14].

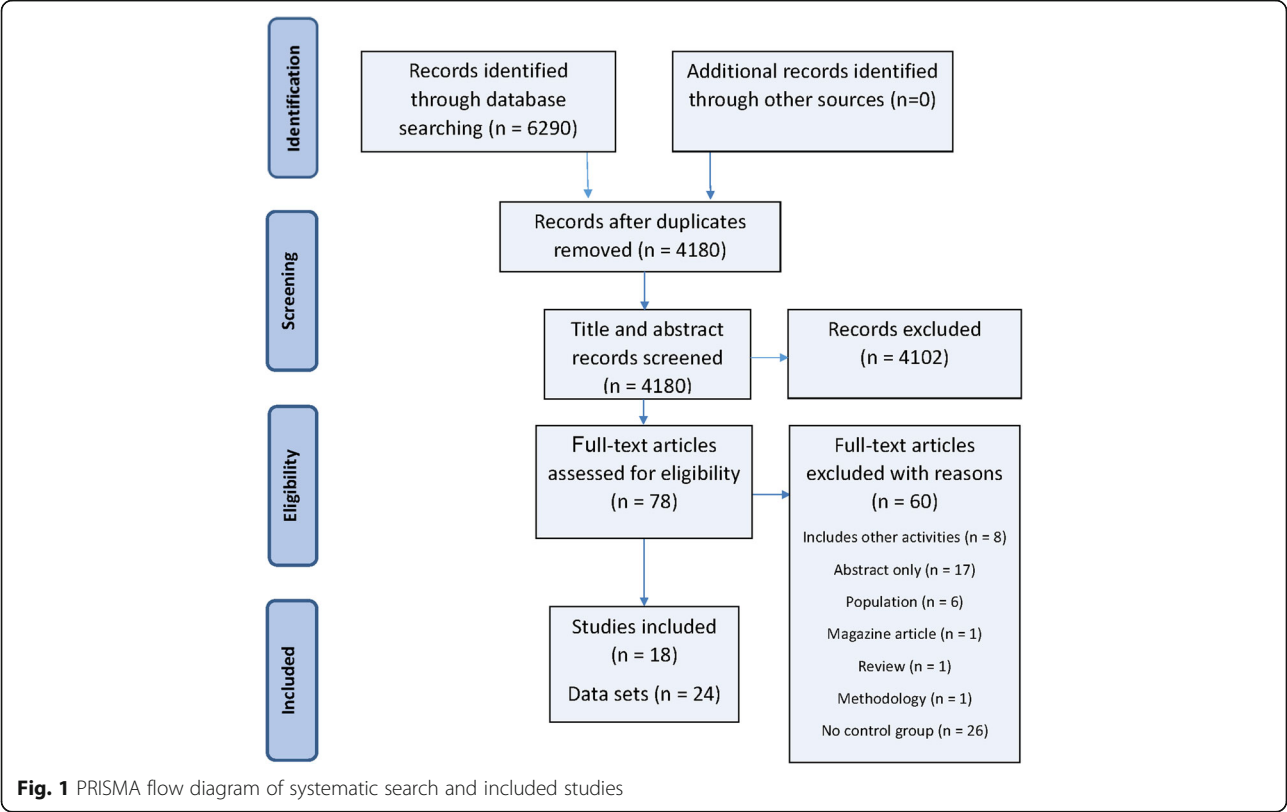
Since the focus of the published reviews has been on obese and overweight youth, or on multicomponent interventions, the isolated role of RT on weight status in youth is not currently known. Further to this, the only review to focus on both healthy weight and overweight/obese youth to date is a decade old. Therefore, the purpose of this review was to systematically examine the impact of resistance training interventions on weight status in youth.

Methods

The search strategy and inclusion criteria were specified and documented in advance on PROSPERO (number CRD42016038365). The conduct and reporting of this review adhered to the guidelines outlined in the PRISMA statement [15]. The PRISMA flow diagram detailing the systematic search and included studies is shown in Fig. 1.

Search strategy

Electronic literature databases were searched from the year of their inception up to and including June 2017. These were PubMed, MEDLINE, ERIC, PsycINFO, Embase, Sport Discus and Scopus. Relevant references from published literature were followed up and included when they met the inclusion criteria and literature not identified in the electronic searches was sourced. ResearchGate was used to identify research papers written by key researchers in the field. Additionally, these researchers were contacted regarding any literature not yet published and the authors of this review searched their personal libraries.



The search terms were related to weight status, youths and RT (Table 1). The Boolean operator “AND” was used between categories, and the phrase “OR” was used within categories. The search strategy was adapted for each database, and searches were logged.

The screening and data extraction process was undertaken by HC and AD. Titles of potentially relevant articles were retrieved using the search strategy, duplicates then removed, and then the titles and abstracts were screened by HC. Ten percent ($n = 418$) of the titles and abstracts were also screened by AD. The inter-rater reliability for the two authors was found to be Kappa = 0.897 suggesting a strong level of agreement [16]. Full-text copies were obtained for potentially eligible articles and assessed for inclusion by HC and AD. During the review of full-text articles, a majority decision was taken in consultation with the other authors when disagreements regarding inclusion/exclusion occurred.

The inclusion/exclusion criteria

Studies with participants of school age between 5 and 18 years were included. No studies were included where the subject group were identified as having a pathological condition or disability which affects movement, (e.g. cerebral palsy/dyspraxia) and no studies were included where the subject group was identified as having a behavioural or neuropsychological condition (e.g. autism or ADHD).

To allow an isolated review of strength training, studies included RT methods but were excluded if they contained plyometric, vibration or neuromuscular training, or training specifically for rehabilitation purposes. Additionally, studies were excluded if the warm up and cool down activities were more than 10 min duration each to ensure there was not a significant aerobic component in the intervention. Studies targeting physical activity or diet were not included unless both the control group and intervention group received the same dietary

Table 1 Systematic review categories and search terms

Target population	Resistance training	Weight status
Youth ^a , young, child ^a , teen ^a , adol ^a , pube ^a , boys, girls	Resistance training, resistance program ^a , resistance intervention, resistance exercise, weight training, strength and conditioning	Weight, body composition, body mass, obese ^a , overweight, skinfold ^a , adiposity, waist, fat, dexa, BodPod

^aSearch term truncated

and physical activity intervention, but the intervention group received a different RT input. There was no restriction on location (e.g. school based or sports centre) or timing (e.g. during or after school).

Although studies were included that used a control group and also those that did not, for the purpose of this paper, the analysis focused on studies that included a control group, and therefore are referred to as controlled trials (CTs). Objective measures included a measure of weight status through body mass, body mass index (BMI), skinfolds, DEXA scans, BodPod, MRI scans, waist circumference, hip circumference or waist to hip ratio.

It is important to note that studies were only included when weight status was mentioned as an aim of the study in the abstract and not just as a demographic characteristic of the participants.

Data extraction

Data were extracted using an electronic form by HC and included study characteristics (e.g. country, year); participant characteristics (e.g., age, sex); intervention components (e.g. setting, content); and changes in the outcomes (e.g. change in weight status). The outcome data were extracted in the form of mean, standard deviation and sample size. If the outcome data was not visible within the paper, authors were contacted and asked to provide this data within a set time frame. To check reliability, AD carried out data extraction on the first 10% of the included studies, which were in alphabetical order of the first author. Following this, any disagreements were resolved through discussion with all authors.

Methodological quality and risk of bias assessment

The “Quality Assessment Tool for Quantitative Studies” developed by the Effective Public Health Practice Project in 1998 [17] was used to assess the quality and risk of bias of the included studies. The results of the assessment lead to an overall methodological rating of strong, moderate or weak in eight sections: selection bias, study design, confounders, blinding, data, collection methods, withdrawals and dropouts, intervention integrity and analysis. The assessment tool has been found to be valid and reliable [18]. To check reliability, AD carried out this assessment on 10% of the included studies and any disagreements were resolved through discussion between the two authors. Overall, the data extraction and risk of bias accuracy of one author was deemed to be acceptable.

Meta-analysis

Random effects meta-analyses were conducted with the Comprehensive Meta-analysis software (version 2.2.064). Hedges’ g with randomised effects and 95% CIs were calculated for trials with sufficient data. The magnitude of

Hedges’ g was interpreted using Cohen’s (1988) [19] convention as small (0.2), medium (0.5) and large (0.8). A significance level of $p \leq 0.05$ was applied. Heterogeneity was assessed using the I^2 statistic. For interpretation, I^2 values of 25, 50 and 75 were considered to indicate low, moderate and high heterogeneity, respectively [20]. Publication bias was assessed by calculating Egger bias statistics [21] and Rosenthal’s fail-safe N [22]. Corresponding funnel plots were created.

A moderator analysis was conducted to determine whether the intervention effects on the outcomes differed by sex of participants (males or females), sex of training group (i.e. the training group was designed for either males, females or mixed sex), weight status (healthy weight, overweight, obese or mixed weight status), age (< 12 or > 12 years, based on primary and secondary school age split), pubertal stage ($<$ Tanner stage 2 or $>$ Tanner stage 2, based on pre-pubertal and post-pubertal stages), location (school during P.E, school during free time or community), type of control (no resistance training, nutrition input only, normal activity, wait list) and quality of study (weak, moderate or strong). Additional moderator analyses were planned for ethnicity and supervised compared to self-regulated sessions. However, there was insufficient data to allow these analyses. Although data was also extracted for frequency and duration of interventions, a moderator analysis was not conducted on this data due to the inappropriateness of separating their independent and combined impact on training outcomes.

It is important to note that for outcomes where a decrease in score was a positive intervention effect (e.g. BMI) and an increase in score was a positive effect (e.g. fat free mass), this was accounted for in the analysis.

Results

Out of an initial 6290 studies identified through database searches, 18 studies met the inclusion criteria and included sufficient data for the meta-analysis. Twenty four data sets were included in the meta-analysis (some studies had more than one intervention group).

Study characteristics

The surveyed studies were conducted in eight different countries (USA, Australia, New Zealand, Hong Kong, Brazil, Tunisia, Austria and Japan). In total, there were 554 participants in the experimental groups (sample sizes ranged from 8 to 78 participants) and 599 participants in the control groups (sample sizes ranging from 5 to 129 participants).

The age of all participants ranged from 8 to 16 years. Eight outcomes related to weight status were included in the analysis: body mass (kg), BMI (kg/m^2), body fat (%), fat-free mass (kg), fat mass (kg), lean mass (kg), skinfolds (mm) and waist circumference (cm). The average attendance for the

studies that reported it was 88%. The study details included in the analysis can be found in Table 2.

Synthesis of results

For each study, Hedges' g was calculated for each outcome variable to determine an overall intervention effect. Figure 2 illustrates effect sizes for all of the studies and the overall effect size for each outcome, which ranged from 0.024 to 0.274, indicating a trivial to small intervention effect relative to controls. Significant intervention effects were identified for body fat (%) (Hedges' $g = 0.215$, 95% CI 0.059 to 0.371, $P = 0.007$) and skinfolds (mm) (Hedges' $g = 0.274$, 95% CI 0.066 to 0.483, $P = 0.01$). Effect sizes were not significant for body mass (Hedges' $g = 0.043$, 95% CI -0.103 to 0.189, $P = 0.564$), body mass index (Hedges' $g = 0.024$, 95% CI -0.205 to 0.253, $P = 0.838$), fat-free mass (Hedges' $g = 0.073$, 95% CI -0.169 to 0.316, $P = 0.554$), fat mass (Hedges' $g = 0.180$, 95% CI -0.090 to 0.451, $P = 0.192$), lean mass (Hedges' $g = 0.089$, 95% CI -0.122 to 0.301, $P = 0.408$) or waist circumference (Hedges' $g = 0.209$, 95% CI -0.075 to 0.494, $P = 0.149$).

Based on the thresholds categorised [20], moderate to high heterogeneity was identified for BMI and waist circumference. For all other outcomes, heterogeneity was low.

Publication bias

To identify possible publication bias, effect sizes were plotted against standard errors to generate funnel plots as illustrated in Fig. 3. There was no indication of publication bias with no statistically significant result from Egger's test [21]. Rosenthal's fail-safe N [22] found that 241 additional studies would be needed for the cumulative effect to be non-significant. Therefore, it can be concluded that the meta-analysis provides a satisfactory representation of the effect of a RT intervention on weight status.

Quality appraisal

Through the quality appraisal process, 44% of the included studies were classified as 'strong', 50% were classified as 'moderate' and 6% were classified as 'weak'.

Moderator analysis

The results (Table 3) suggest a moderation effect of weight status on BMI and waist circumference, with significant differences between healthy weight, mixed weight, overweight/obese and obese participants. The results suggest a moderation effect of quality score on waist circumference, with significant differences between strong and moderate studies.

Discussion

Summary of evidence

The purpose of this meta-analysis was to examine the effect of resistance training (RT) interventions on weight status in youth. In summary, there was a small, statistically significant, effect of RT interventions on body fat % and skinfolds, but no overall significant effect on body mass, BMI, fat-free mass, fat mass, lean mass or waist circumference.

The UKSCA's [8] and NSCA's [7] position statements on youth RT both suggest that RT may have a positive impact on body fat and the significant findings of this meta-analysis for body fat % and skinfolds support these statements.

While more studies are required to provide further understanding of the mechanism underlying a reduction in body fat due to a RT intervention, it has been reported that a possible cause could be due to an increase in skeletal muscle mass and resulting increase in basal metabolic rate [23], in particular, this has been noted in adolescents [8]. However, as there were no overall significant effect sizes evident for lean mass or fat free mass in this analysis, this suggests that these changes could possibly be due to increases in overall energy expenditure that may have occurred by simply taking part in an active intervention, rather than an increase in metabolically active lean tissue. It is important to note, however, that with data from both pre-pubertal and post-pubertal participants included in the analysis, this may have had an impact on the results.

Although all of the studies that measured fat mass were in favour of the intervention, this result was not significant and the effect size was trivial. It is worth considering why the effects were not consistent across different measures of body fat. Although body scans have been used in the included studies to measure both body fat % and fat mass, studies that have used skinfolds to measure body fat % have also been included in the analysis. DEXA scans measure both subcutaneous and visceral fat; however, skinfolds measure subcutaneous fat only. As there have been variable findings with regards to the impact of training on different locations of fat [24–28], this could explain why there were significant findings for body fat % and skinfolds, but not for fat mass. This emphasises the importance of validity when selecting measurement tools and methods used to assess intervention outcomes indicative of body fat. An additional factor to consider in this meta-analysis is that there was more than double the number of studies that investigated body fat % as an outcome in comparison to fat mass, providing greater statistical power to the findings for body fat %.

Resistance training did not demonstrate a significant effect on body mass or BMI; however, due to growth,

Table 2 Description of included studies/data sets (Continued)

Study	Country	Participant details			Intervention details			Outcome measures	Quality score				
		N	Age (years± SD) or range	Pubertal stage (Tanner)	Weight status	% males	Sex of training group			Location	Weeks/× per week (min per session)	Sets/reps /intensity	Exercises
Faigenbaum et al. 1993 [38]	USA	EG 14	EG 10.8	1–2	Healthy	68%	Mixed	/	8 weeks/× 2 (35 m)	3 sets, 10–15 reps, 50–100%1RM	Leg extension, leg curl, overhead press, bicep curl, chest press	Body mass (kg), skinfolds (mm), waist circumference (cm)	2
		CG 10	CG 9.9										
Lau et al. 2004 [30]	Hong Kong	EG 21	EG 10–17	/	Obese	68%	Mixed	Community	6 weeks/× 3(60 m)	3 sets > 5reps, 70–75%1RM	Chest press, lat pull down, shoulder press, leg press, leg extension, leg curl, heel raise, bicep curl, tricep extension, adjusted push-up	Body mass (kg), Body mass index (BMI), waist circumference (cm), hip circumference (cm), waist to hip ratio, lean mass (kg), fat mass (kg), body fat (%)	2
		CG 17											
Lillegaard et al. 1997 (a) [39]	USA	EG 20	EG 11.2	1–2	Healthy	100%	Mixed	/	12 weeks/× 3(60 m)	3 sets, 10 reps, 10RM	Barbell curl, tricep extension, leg press, leg curl, lat pulldown, bench press	Skinfolds (mm)	3
		CG 18	CG 10.1										
Lillegaard et al. 1997 (b) [39]	USA	EG 16	EG 14	3–5	Healthy	100%	Mixed	/	12 weeks/× 3(60 m)	3 sets, 10 reps, 10RM	Barbell curl, tricep extension, leg press, leg curl, lat pulldown, bench press	Skinfolds (mm)	3
		CG 10	CG 13.1										
Lillegaard et al., 1997 (c) [39]	USA	EG 8	EG 9.5	1–2	Healthy	0%	Mixed	/	12 weeks/× 3 (60 m)	3 sets, 10 reps, 10RM	Barbell curl, tricep extension, leg press, leg curl, lat pulldown, bench press	Skinfolds (mm)	3
		CG 6	CG 9.6										
Lillegaard et al. 1997 (d) [39]	USA	EG 8	EG 12.6	3–5	Healthy	0%	Mixed	/	12 weeks/× 3 (60 m)	3 sets, 10 reps, 10RM	Barbell curl, tricep extension, leg press, leg curl, lat pulldown, bench press	Skinfolds (mm)	3
		CG 5	CG 12.6										
Lubans et al. 2010 (a) [40]	Australia	EG 15	EG 14.9 ± 0.6	/	Mixed	0%	Mixed	School—free time	8 weeks/× 2 (50 m)	2 sets, 8–12 reps, max reps	Squat, lunge, calf raise, bent over row, bench press, front raise, biceps curl, triceps extension, crunch and Russian twist	Body mass (kg), waist circumference (cm), body mass index (BMI), fat mass (kg), fat free mass (kg), body fat (%)	2
		CG 16	CG 14.5 ± 0.6										
Lubans et al.	Australia	EG	EG 15.3 ± 0.8	/	Mixed	100%	Mixed	School—free	8 weeks/× 2	2 sets, 8–12	Squat, lunge, calf raise, bent	Body mass (kg),	2

Table 2 Description of included studies/data sets (Continued)

Study	Country	Participant details				Intervention details				Outcome measures	Quality score		
		N	Age (years± SD) or range	Pubertal stage (Tanner)	Weight status	% males	Sex of training group	Location	Weeks/x per week (min per session)			Sets/reps /intensity	Exercises
2010 (b) [40]		22						time	(50 m)	reps, max reps	over row, bench press, front raise, biceps curl, triceps extension, crunch and Russian twist	waist circumference (cm), body mass index (BMI), fat mass (kg), fat free mass (kg), body fat (%)	1
		CG 14	CG 14.8±0.4										
Schranz et al. 2014 [41]	Australia	EG 30	EG 14.9±1.4	2+	O/W obese	100%	Males	Community	24 weeks/x 3	1–3 sets, 8–12 reps, progress with good form	Bench press, leg press, lat pulldown, leg curl (lying or seated), shoulder press (seated), seated row, biceps curl, triceps pressdown, calf raise (seated) and abdominal crunch.	Body mass (kg), body mass index (BMI), skinfolds (mm), body fat (%), lean mass (kg)	2
		CG 26	CG 15.1±1.6										
Schwingshandl et al. 1999 [42]	Austria	EG 14	EG 11±2.5	/	Obese	43%	Mixed	Community	12 weeks/x 2 (60 m)	2 sets, 10 reps, 50–100%1RM	Lying leg press; seated leg extensions and leg curls; seated bench press; lat pulldown to the front and long pulley row; seated shoulder press; triceps pushdowns and triceps extension at the dips machine; dumbbell biceps curls; calf raises seated and crunches	Body mass (kg), body mass index (BMI) SDS, fat free mass (kg)	1
		CG 16	CG 12.2±2.7										
Shaibi et al. 2006 [43]	USA	EG 11	EG 15.1±0.5	3+	O/W	100%	Males	Community	16 weeks/x 2	1–3 sets, 3–15 reps, 52–97%1RM	session 1 = Leg press, dead lift, biceps curl, triceps extension, shoulder press, session 2 = bench press, lat pull down, leg extension, leg curl calf raises	Body mass (kg), body mass index (BMI) percentile, lean mass (kg), body fat %	1
		CG 11	CG 15.6±0.5										
Siegel et al. 1989 (a) [44]	USA	EG 26	EG 8.4	/	Healthy	100%	Mixed	School—free time	12 weeks/x 3 (30)	30 s work, 15 s rest, progress to 45 s work circuit training, body weights and weights up to 4.5lbs	Upper body self-supported locomotor movements (i.e., wheelbarrow, seal walk, crabwalk, etc.). A choreographed weight routine used tennis ball cans or detergent bottles filled with sand. Weights of 2.5, 3.0, 3.5, 4.0, and 4.5 lb. were offered. The third format was circuit training using various types of	Body mass (kg), skinfolds (mm), body fat (%)	1
		CG 30	CG 8.6										

Table 2 Description of included studies/data sets (Continued)

Study	Country		Participant details				Intervention details			Outcome measures		Quality score
	N	Age (years $\pm$ SD) or range	Pubertal stage (Tanner)	Weight status	% males	Sex of training group	Location	Weeks/ $\times$ per week (min per session)	Sets/reps /intensity	Exercises		
Siegel et al. 1989 (b) [44]	USA	EG 8.7 24 CG 8.4 16	/	Healthy	0%	Mixed	School—free time	12 weeks/ $\times$ 3 (30)	30 s work, 15 s rest, progress to 45 s work, circuit training, body weights and weights up to 4.5lbs	accessories as resistance, tennis balls for squeezing, and strips of rubber tire to pull Upper body self-supported locomotor movements (ie, wheelbarrow, seal walk, crabwalk, etc.). A choreographed weight routine used tennis ball cans or detergent bottles filled with sand. Weights of 2.5, 3.0, 3.5, 4.0, and 4.5 lb. were offered. The third format was circuit training using various types of accessories as resistance, tennis balls for squeezing, and strips of rubber tire to pull	Body mass (kg), skinfolds (mm), body fat (%)	1
Sigal et al. 2014 [29]	Canada	EG 15.9 $\pm$ 1.5 CG 15.6 $\pm$ 1.3 76	4–5	Obese	31%	Mixed	Community	24 weeks/ $\times$ 4	2–3 sets, 6–15 reps, moderate for 15 reps then 8RM	1: Bench press, chest fly lateral raise, shoulder, shrugs, bicep curl, tricep press, abdominal crunches. 2: Incline bench press, incline chest fly, shoulder press, front raise, preacher curl, assisted tricep dips, sit-ups. 3: Squat, leg curl, front lat pull down, seated row, lunge straight leg raise, abdominal crunches. 4: Leg press, leg extension, dumbbell pullover, seated row, lying knee extensions	Body mass (kg), body mass index (BMI), waist circumference (cm), body fat (%), fat mass (kg), lean mass (kg)	1
Takai et al. 2013 [45]	Japan	EG 13.6 $\pm$ 0.6 CG 13.8 $\pm$ 0.5 58	/	Healthy	100%	males	School—free time	8 weeks/ $\times$ 4–6 (> 10 m)	100 reps, body weight	Squats	Body mass (kg), body mass index (BMI), body fat %, lean mass (kg)	1
Treuth et al. 1998 [27]	USA	EG 8.7 $\pm$ 0.7 CG 8.4 $\pm$ 0.9 11	1–2	Obese	0%	Females	School—free time	20 weeks/ $\times$ 3 (20 m)	2 sets, 12–15 reps, 50%1RM	Bench press, military press, lat pull down, bicep curl, tricep extension, ab curls, leg press	Body mass (kg), body fat (%), fat mass (kg), lean mass (kg), fat mass (kg), fat	1

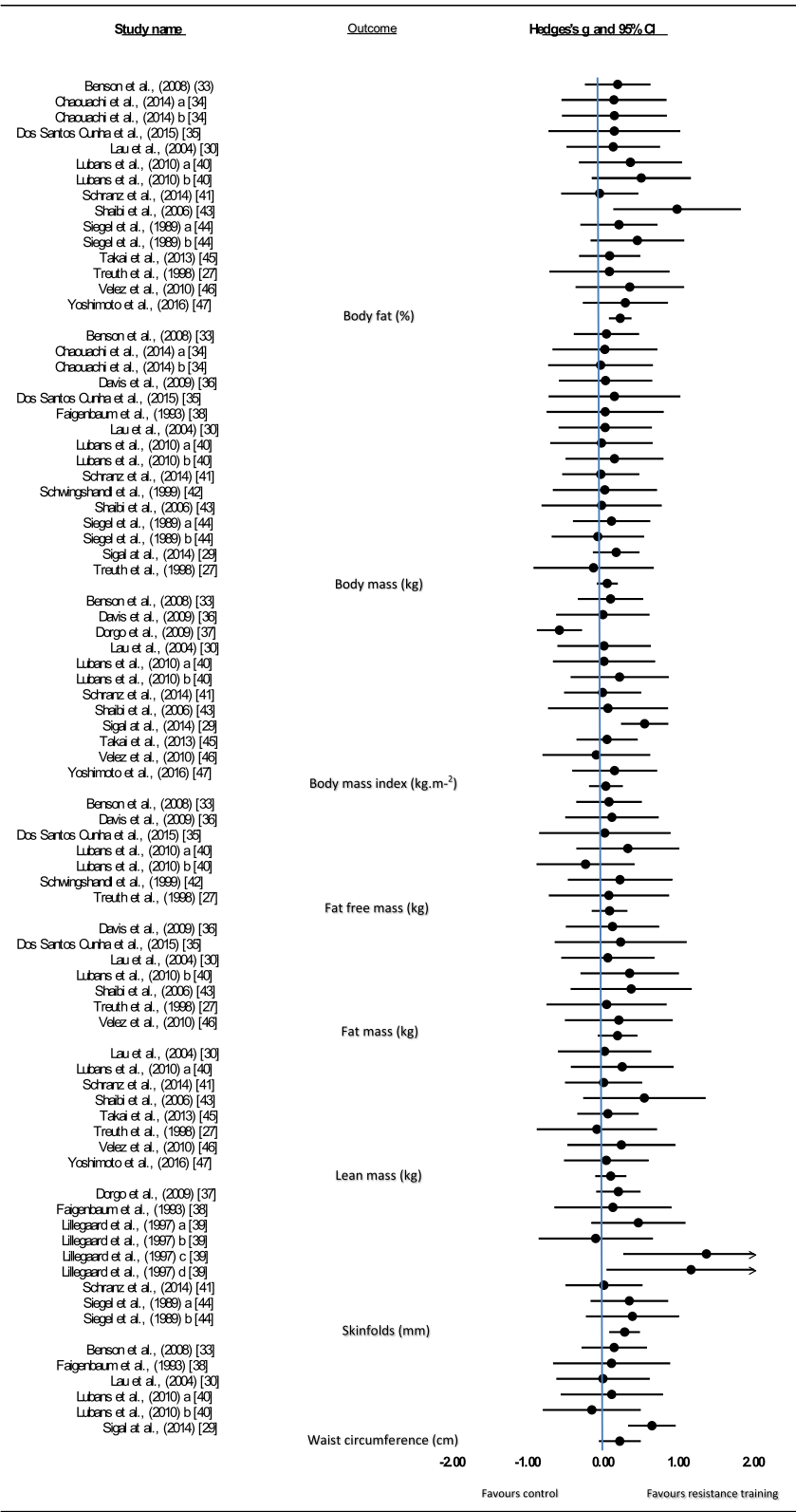


Fig. 2 Summary of all weight status meta-analyses

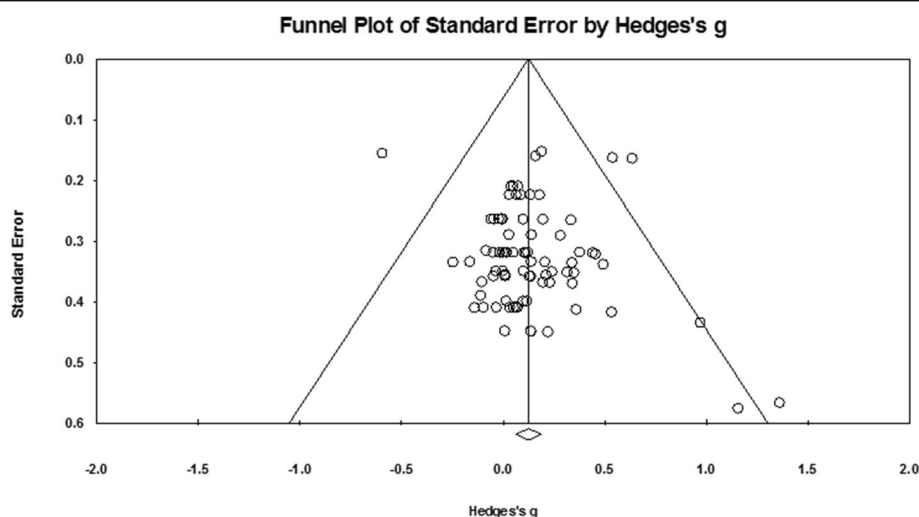


Fig. 3 Funnel plot

these results should be interpreted with caution. Since the studies included in the analysis assessed a combination of healthy weight, overweight and obese participants, changes in these measures over time are likely to be variable and this is explored further in the moderator analysis discussed below. For the purpose of this analysis, a decrease in body mass and BMI was analysed as a favourable change. However, with the interventions being resistance based, a subsequent increase in lean mass/fat-free mass (and therefore body mass) was possible, and this may have obscured the findings with an overall positive trend for RT impacting on lean mass and fat free mass in this analysis. It has been identified that there is mixed evidence with regards to whether youth may experience increases in muscle mass following RT, most likely due to inadequate levels of circulating testosterone [7] although it has been suggested that resistance training may develop lean body mass in adolescents [8]. This will have been exacerbated by the inclusion of youth from 8 to 16 years of age of varying pubertal status and by varying intervention duration. It has also been suggested that periods of training in excess of 10 weeks are required for increases in lean muscle mass to occur [10]. In this review, for lean mass, 67% of the data sets were from studies that included interventions that were > 10 weeks, and for fat-free mass, these interventions were > 10 weeks for only 50% of the studies. This suggests that the intervention duration for several of the studies may not have been long enough to invoke positive measurable changes.

For the outcome of waist circumference, there was no significant effect size evident. With a combination of healthy weight, overweight and obese participants, it might be expected that those studies including overweight/obese participants would show a larger effect on

waist circumference than the studies that included healthy weight participants, and this is further explained by the moderator analysis discussed below. There were two studies that included obese participants only; one finding a large effect of the intervention on waist circumference [29] and the other finding no significant effect [30]. In the 2004 study, the authors did identify that with only a 6-week intervention, this may not have been long enough to have a positive impact on the measured outcomes. Additionally, only six studies investigated waist circumference as an outcome, and this outcome therefore had less statistical power than some of the others.

Previous reviews

Overall, these findings are similar to previous reviews. In a meta-analysis published in 2013 [12], there was a significant effect of interventions including a RT component on body fat % in overweight or obese youths. They also reported no significant effect sizes for body mass, BMI waist circumference, fat mass or lean mass. Out of the 40 studies included, only 9 studies were RT-only studies, and out of these 9, 6 were CTs. However, although interventions were included that also incorporated an aerobic and/or dietary component, similar effects were found for studies that included interventions that were RT alone when authors performed a sub-analysis. There were only three studies included that incorporated RT only and therefore interpreting the data should be undertaken with caution.

In a further systematic review [11], only six studies were included that investigated RT only interventions in overweight/obese youth. Three out of the six studies showed a significant decrease in percentage fat and a significant increase in fat-free mass, although none of

Table 3 Moderator analysis

Moderator	Outcome	Hedges'g (95% CI)	No. of studies	Between group comparison: Q (df)
Sex of participants	Skinfolds (mm)	Females = 0.815 (0.167 to 1.463)*	3	3.310 (2)
		Males = 0.188 (− 0.105 to 0.482)	4	
		Mixed = 0.181 (− 0.100 to 0.462)	2	
Sex of training group	Body fat (%)	Mixed = 0.277 (0.055 to 0.500)*	7	0.660 (2)
		Males = 0.139 (0.− 0.108 to 0.387)	6	
		Females = 0.212 (− 0.254 to 0.678)	2	
	Skinfolds (mm)	Mixed = 0.320 (0.094 to 0.545)**	8	1.214 (1)
		Males = − 0.001 (− 0.519 to 0.517)	1	
Weight status	Body mass index (kg/m ²)	Obese = 0.540 (0.220 to 0.860)**	1	8.586 (3)*
		Healthy = − 0.172 (− 0.668 to 0.324)	3	
		Mixed = 0.063 (− 0.231 to 0.358)	4	
		Overweight/obese = − 0.003 (− 0.313 to 0.307)	4	
	Body fat (%)	Mixed = 0.301 (0.005 to 0.598) *	4	0.374(2)
		Healthy = 0.189 (− 0.032 to 0.410)	7	
		Overweight/obese = 0.198 (− 0.203 to 0.598)	4	
	Skinfolds (mm)	Healthy = 0.320 (0.094 to 0.545)**	8	1.241 (1)
		Overweight/obese = − 0.001 (− 0.519 to 0.517)	1	
	Waist circumference (cm)	Obese = 0.636 (0.314 to 0.958)***	1	7.586(3)*
		Healthy = 0.100 (− 0.684 to 0.884)	1	
		Mixed = 0.056 (− 0.267 to 0.379)	3	
		Overweight/obese = − 0.015 (0.083 to 0.497)	1	
Age	Body fat (%)	> 12 = 0.211 (0.016 to 0.407)*	8	0.004(1)
		< 12 0.222 (− 0.036 to 0.480)	7	
	Skinfolds (mm)	< 12 = 0.415 (0.116 to 0.714) **	5	1.294 (1)
		> 12 = 0.165 (− 0.146 to 0.476)	4	
Pubertal stage	Skinfolds (mm)	< 2 = 0.415 (0.116 to 0.714) **	5	0.392 (1)
		> 2 0.199 (− 0.7407 to 0.805)	3	
	Waist circumference (cm)	> 2 = 0.636 (0.314 to 0.958) ***	1	0.536(1)
		< 2 = 0.100 (− 0.684 to 0.884)	1	
Location	Body mass index (kg/m ²)	School free time = 0.277 (0.069 to 0.485)*	5	2.152(2)
		School PE = − 0.103 (− 0.825 to 0.618)	1	
		Community = 0.027 (− 0.227 to 0.280)	5	
	Body fat (%)	School free time = 0.256 (0.030 to 0.483)*	6	0.337(2)
		School PE = 0.259 (− 0.301 to 0.820)	2	
Quality score	Body fat (%)	Community = 0.164 (− 0.069 to 0.397)	7	0.282 (2)
		Moderate = 0.269 (0.001 to 0.537)*	5	
		Weak = 0.135 (− 0.363 to 0.632)	2	
	Waist circumference (cm)	Strong = 0.197 (− 0.011 to 0.405)	8	7.528 (1)**
		Strong = 0.636 (0.314 to 0.958)**	1	
		Moderate = 0.048 (− 0.221 to 0.317)	5	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

the studies found a decrease in total fat mass, which is in support of the findings of this review. Four studies reported significant changes in body composition, with an

increase in fat-free mass and BMI and additionally, all studies reported an increase in body weight. This is conflicting with the current review, although their review

only included overweight and obese youth. Unlike the studies in the current analysis, all studies in their review included RT of moderate to submaximal intensity during treatment, rather than high intensity work and while acknowledging the limitations of using percentage of 1RM to prescribe intensity, higher intensity work (however calculated) will provide a greater stimulus for overload than low-medium intensity work. This may have had an impact on their overall findings with regards to weight status, as high intensity work has been reported as a key component to elicit changes in body composition [10]. Supporting the variable findings with regards to the impact of RT on obese adolescents, inconclusive results were found from just seven studies included that focused on RT alone [10].

In the only systematic review to date that included both healthy weight and overweight/obese participants, 12 studies were included [14]. It was reported that for CTs, no studies found a significant change in BMI body fat, two studies reported a change in lean body mass and one study that reported a change in waist circumference. In their review, there were only five RCTs and three of these included a dietary and/or aerobic component. The interventions were also different to the current review with all but two of the RT interventions being circuit based.

Overall, with just one of the reviews described above including a meta-analysis, it makes comparisons with the current meta-analysis somewhat challenging.

Moderator analysis

To investigate the findings further, a moderator analysis was completed on all outcomes to identify if any effects could be explained by specific moderator variables. It was found that weight status was a moderator for BMI and waist circumference, and these outcomes showed moderate and high heterogeneity respectively and therefore the variance between studies could be explained by weight status. All other outcomes did not display significant heterogeneity, and no significant findings were apparent from the moderator analysis (Table 2).

There was a significant effect of the intervention on the BMI and waist circumference of obese participants (Table 2) but not on other weight categories, indicating that RT could be an effective intervention on these outcomes in obese individuals. It would seem plausible that BMI and waist circumference outcomes would vary significantly across studies due to the inclusion of both healthy weight and overweight/obese participants. It has been reported that obese youth are more sedentary than their healthy weight peers [31] and require more energy to move [32]. Therefore, an increase in physical activity might have a larger relative increase in energy expenditure reflected in reduced BMI and waist circumference.

It should be noted, however, that for waist circumference, there were only six studies included in the analysis. Three were mixed weight with one study each for obese, overweight and healthy weight participants. This small number of studies may explain the high heterogeneity, and therefore interpreting the results should be undertaken cautiously. Additionally, a longer term follow up study would be beneficial to investigate resistance training as an obesity prevention method.

These findings conflict with previous findings [12] that suggested that there was a very small moderation effect of age and sex on various weight status outcomes. It was reported that for youth 12 years or older, there was an intervention effect on body mass, BMI, waist circumference, body fat %, fat mass and lean mass, and for males, there was an intervention effect on body mass, BMI, body fat % and fat mass. However, these were small influences on intervention effects, and their analysis included studies that incorporated an aerobic or dietary component which is different to the analysis in the current review and therefore it is difficult to make conclusions regarding RT alone based on their findings.

Strengths and limitations

There were a number of strengths to this review. There should be strong confidence in the main findings given the rigorous review process. A strict inclusion/exclusion criteria resulted in an analysis of 24 data sets that examined the effects of RT on weight status in 554 youths from 8 countries.

This is also the first meta-analysis to include healthy weight and overweight/obese participants taking part in RT only interventions, which is important to identify the impact of RT not only as a treatment for obesity but also as a prevention.

There was high compliance reported in the included studies. For the studies who reported it, compliance was 88%. As well as a strength of the current meta-analysis, high compliance adds substance to the potential for RT as a viable mode of intervention to improve weight status.

There are however limitations that need to be considered when interpreting the results. There was large variability within the study interventions with regards to participant numbers (ranging from 5 to 129 participants), frequency, duration and programme content. The frequency ranged from 2 to 6 times a week and duration ranged from 8 to 20 weeks. Programmes also involved a mixture of sets and reps with a range of intensities and some being circuit based. The forest plots also indicate large variation with the individual studies' results.

For certain outcomes there were a variety of different methods of measurement. For example, body fat % was measured by DEXA, BodPod, bioelectrical impedance

scales, skinfolds and MRI scanning. While reporting standardised mean differences allowed us to pool the data for the purposes of the meta-analysis, differences between measurement tools should be acknowledged.

A limitation of the moderator analysis was not all of the studies reported data to enable a thorough investigation, so limited conclusions can be made based on this additional, incomplete level of analysis.

Finally, there was a mixture of quality of the studies included, with only 44% of the studies classified as 'strong'. When moderating for quality of studies, it is difficult to make conclusions despite there being significant findings for waist circumference, as there was only one 'strong' study for this outcome. This had a large effect size in comparison to the 'moderate' and 'weak' studies.

Conclusions

The literature suggests that RT may have a positive effect on weight status in youth, although the effects have not been clearly established and it is clear that more quality research is required to investigate this further. This meta-analysis provides an overview of the current research evidence and an insight into the potential benefits of such interventions. It adds to previous systematic reviews by including both healthy weight and overweight/obese youths and including RT only interventions which explores not only the treatment of obesity, but also prevention which is a vital component in combatting rising levels of obesity in children.

Overall, this meta-analysis found a small, statistically significant effect of RT interventions on body fat % and skinfolds, but no overall significant effect on body mass, BMI, fat free mass, fat mass, lean mass or waist circumference. While we can conclude that RT interventions have a small positive impact on some indicators of weight status, it is noted that this reflects only a small body of published work.

With RT interventions offering potential benefits for youth with regards to weight status, it is imperative that more robust and quality studies should be conducted to further, and unequivocally, investigate the role RT may play in the treatment and prevention of obesity. Based on the findings of this meta-analysis, and in support of the conclusions of previous reviews, future studies should be designed as randomised controlled trials with large samples and include a treatment group with an isolated RT intervention. There should be careful consideration into appropriate intervention content and assessment methods. If validated, this type of intervention, as recommended by the UK and WHO physical activity guidelines, could ultimately have a positive impact on the prevalence of common obesity-related diseases, such as type 2 diabetes, cardiovascular disease and cancer, and improve the health of individuals not only during childhood but as they progress through life.

Acknowledgements

We would like to thank all authors who responded to our requests for additional information.

Availability of data and materials

After publication, all data necessary to understand and assess the conclusions of the manuscript are available to any reader of *Sports Medicine-Open*.

Authors' contributions

HC, SF, JB and AD all participated in the study design, protocol and registration. HC and AD were responsible for selecting articles for inclusion and conducted the risk of bias assessment. HC and AD were responsible for data extraction. HC and JB contributed to the data analysis. HC drafted the manuscript and all authors provided critical input and final approval.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors Helen Collins, Samantha Fawcner, Josephine N Booth and Audrey Duncan declare that they have no competing interests.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details

¹Institute of Sport and Exercise, University of Dundee, Old Hawkhill, Dundee DD14HN, UK. ²Physical Activity and Health Research Centre, University of Edinburgh, Edinburgh, UK. ³Moray House School of Education, University of Edinburgh, Edinburgh, UK.

Received: 24 April 2018 Accepted: 1 August 2018

Published online: 20 August 2018

References

- World Health Organization. Obesity and overweight. 2016. Available from: <http://www.who.int/mediacentre/factsheets/fs311/en/> Accessed 09/11/17.
- Ogden CL, Carroll MD, Curtin LR, et al. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA*. 2006;295(13):1549-55.
- World Health Organization. Global Recommendations on Physical Activity for Health. Geneva: WHO Press; 2010.
- Chief Medical Office. UK Physical Activity Guidelines. 2011. Available from: <https://www.gov.uk/government/publications/uk-physical-activity-guidelines> Accessed 1.10.17.
- Health Behaviour in School-aged Children (HBSC) survey. Physical activity in adolescents. 2013/14. Available from: http://www.euro.who.int/__data/assets/pdf_file/0018/303480/HBSC-No.7_factsheet_Physical.pdf?ua=1 Accessed 09/11/17.
- Van Sluijs EM, McMinn AM, Griffin SJ. Effectiveness of interventions to promote physical activity in children and adolescents: systematic review of controlled trials. *BMJ*. 2007;335(7622):703.
- Faigenbaum AD, Kraemer WJ, Blimkie CJR, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res*. 2009;23(5):S60-79.
- Lloyd RS, Faigenbaum AD, Myer GD, et al. UKSCA position statement: youth resistance training. *Prof Strength Cond*. 2012;26:26-39.
- Stratton G, Jones M, Fox KR, et al. BASES position statement on guidelines for resistance exercise in young people. *J Sports Sci*. 2004;22:383-90.
- Alberga AS, Sigal RJ, Kenny GP. A review of resistance exercise training in obese adolescents. *Phys Sportsmed*. 2011;39(2):50-63.
- Dietz P, Hoffmann S, Lachtermann E, Simon P. Influence of exclusive resistance training on body composition and cardiovascular risk factors in overweight or obese children: a systematic review. *Obesity Facts*. 2012;5:546-60.
- Schranz N, Tomkinson G, Olds T. What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and

- obese children and adolescents? A systematic review and meta-analysis. *Sports Med.* 2013;43(9):893–907.
13. Pandita A, Sharma D, Pandita D, et al. Childhood obesity: prevention is better than cure. *Diabetes Metab Syndr Obes.* 2016;9:83–9.
 14. Benson AC, Torode ME, Fiatarone Singh MA. Effects of resistance training on metabolic fitness in children and adolescents: a systematic review. *Obes Rev.* 2008;9(1):43–66.
 15. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Br Med J.* 2009;339:b2535.
 16. McHugh L. Interrater reliability: the kappa statistic. *Biochem Med.* 2012; 22(3):276–82.
 17. Effective Public Health Practice Project. Quality Assessment Tool For Quantitative Studies. 1998. Available from: https://merst.ca/wp-content/uploads/2018/02/quality-assessment-tool_2010.pdf. Accessed 09 Aug 2018.
 18. Thomas BH, Ciliska D, Dobbins M, et al. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews Evid-Based Nurs.* 2004;1(3):176–84.
 19. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale: Lawrence Erlbaum Associates; 1988.
 20. Higgins JP, Thompson SG, Deeks JJ, et al. Measuring inconsistency in meta-analyses. *British Med J.* 2003;327:557.
 21. Egger M, Davey Smith G, Schneider M, et al. Bias in meta-analysis detected by a simple, graphical test. *BMJ.* 1997;315(7109):629–34.
 22. Rosenthal R. The file drawer problem and tolerance for null results. *Psychol Bull.* 1979;86(3):638–41.
 23. Smith JJ, Eather N, Morgan PJ, et al. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med.* 2014;44(9):1209–23.
 24. Slentz CA, Bateman LA, Willis LH, et al. Effects of aerobic vs. resistance training on visceral and liver fat stores, liver enzymes, and insulin resistance by HOMA in overweight adults from STRIDE AT/RT. *Am J Physiol Endocrinol Metab.* 2011;301:E1033–9.
 25. Lee S, Deldin AR, White D, et al. Aerobic exercise but not resistance exercise reduces intrahepatic lipid content and visceral fat and improves insulin sensitivity in obese adolescent girls: a randomized controlled trial. *Am J Physiol Endocrinol Metab.* 2013;305:E1222–9.
 26. Lee S, Bacha F, Hannon T, et al. Effects of aerobic versus resistance exercise without caloric restriction on abdominal fat, intrahepatic lipid, and insulin sensitivity in obese adolescent boys: a randomized, controlled trial. *Diabetes.* 2012;61(11):2787–95.
 27. Treuth MS, Hunter GR, Figueroa-Colon R, et al. Effects of strength training on intra-abdominal adipose tissue in obese prepubertal girls. *Med Sci Sports Exerc.* 1998;30(12):1738–43.
 28. Kordi R, Dehghani S, Noormohammadpour P, et al. Effect of abdominal resistance exercise on abdominal subcutaneous fat of obese women: a randomized controlled trial using ultrasound imaging assessments. *J Manip Physiol Ther.* 2015;38(3):203–9.
 29. Sigal RJ, Alberga AS, Goldfield GS, et al. Effects of aerobic training, resistance training, or both on percentage body fat and cardiometabolic risk markers in obese adolescents: the healthy eating aerobic and resistance training in youth randomized clinical trial. *JAMA Pediatr.* 2014;168(11):1006–14.
 30. Lau PWC, Yu CW, Lee A, et al. The physiological and psychological effects of resistance training on Chinese obese adolescents. *J Exerc Sci Fit.* 2004;2:115–20.
 31. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. *Lancet.* 2002;360(9331):473–82.
 32. Maffei C, Schutz Y, Schena F, et al. Energy expenditure during walking and running in obese and nonobese prepubertal children. *J Pediatr.* 1993;123:193–9.
 33. Benson AC, Torode ME, Fiatarone, et al. The effect of high-intensity progressive resistance training on adiposity in children: a randomized controlled trial. *Int J Obes.* 2008;32:1016–27.
 34. Chaouachi A, Hammami R, Kaabi S, et al. Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training. *J Strength Cond Res.* 2014;28:1483–96.
 35. Dos Santos CG, Sant'anna MM, Cadore EL, et al. Physiological adaptations to resistance training in prepubertal boys. *Res Q Exerc Sport.* 2015;86(2):172–81.
 36. Davis JN, Kelly LA, Lane CJ, et al. Randomized control trial to improve adiposity and insulin resistance in overweight Latino adolescents. *Obesity.* 2009;17(8):1542–8.
 37. Dorgo S, King GA, Candelaria NG, et al. Effects of manual resistance training on fitness in adolescents. *J Strength Cond Res.* 2009;8:2287–94.
 38. Faigenbaum AD, Zaichkowsky LD, Westcott WL, et al. The effects of a twice-a-week strength training program on children. *Pediatr Exerc Sci.* 1993;5(4):339–46.
 39. Lillegaard WA, Brown EW, Wilson DJ, et al. Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity. *Pediatr Rehabil.* 1997;1(3):147–57.
 40. Lubans DR, Sheaman C, Callister R. Exercise adherence and intervention effects of two school-based resistance training programs for adolescents. *Prev Med.* 2010;50(1–2):56–62.
 41. Schranz N, Tomkinson G, Parletta N, et al. Can resistance training change the strength, body composition and self-concept of overweight and obese adolescent males? A randomised controlled trial. *Br J Sports Med.* 2014;48:1482–8.
 42. Schwingshandl J, Sudi K, Eibl B, et al. Effect of an individualised training programme during weight reduction on body composition: a randomised trial. *Arch Dis Child.* 1999;81:426–8.
 43. Shaibi GQ, Cruz ML, Ball GD, et al. Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. *Med Sci Sports Exerc.* 2006;38:1208–15.
 44. Siegel JA, Camaione DN, Manfredi TG. The effects of upper body resistance training on prepubescent children. *Pediatr Exerc Sci.* 1989;2:145–54.
 45. Takai Y, Fukunaga Y, Fujita E, et al. Effects of body mass-based squat training in adolescent boys. *J Sports Sci Med.* 2013;12(1):60–5.
 46. Velez A, Golem DL, Arent SM. The impact of a 12-week resistance training program on strength, body composition, and self-concept of Hispanic adolescents. *J Strength Cond Res.* 2010;24(4):1065–73.
 47. Yoshimoto T, Takai Y, Fukunaga Y, et al. Effects of school-based squat training in adolescent girls. *J Sports Med Phys Fitness.* 2016;56(6):678–3.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com

2.3 The effect of resistance training interventions on fundamental movement skills in youth: a meta-analysis.

SYSTEMATIC REVIEW

Open Access



The effect of resistance training interventions on fundamental movement skills in youth: a meta-analysis

Helen Collins^{1,2,3*} , Josephine N. Booth², Audrey Duncan¹ and Samantha Fawcner^{2,3}

Abstract

Background: Fundamental movement skills (FMS) are strongly related to physical activity (PA) in childhood and beyond. To develop FMS, resistance training (RT) may be a favourable intervention strategy. The purpose of this meta-analysis was to systematically examine the effect of RT interventions on FMS in youth.

Methods: Meta-analysis followed the PRISMA guidelines (Prospero registration number CRD42016038365). Electronic literature databases were searched from the year of their inception up to and including June 2017. The search strategy aimed to return studies that included product and process-oriented measures as a means of assessing FMS. Studies from English language peer-reviewed published articles that examined the effect of RT on indicators of FMS in youth, with participants of school age (5–18 years) were included.

Results: Thirty-three data sets were included exploring five outcomes related to FMS. Studies included only reported product-oriented outcomes. Significant intervention effects were identified for: sprint (Hedges' $g = 0.292$, 95% CI 0.017 to 0.567, $P = 0.038$), squat jump (Hedges' $g = 0.730$, 95% CI 0.374 to 1.085, $P < 0.001$), standing long jump (Hedges' $g = 0.298$, 95% CI 0.096 to 0.499, $P = 0.004$), throw (Hedges' $g = 0.405$, 95% CI 0.094 to 0.717, $P = 0.011$) and vertical jump (Hedges' $g = 0.407$, 95% CI 0.251 to 0.564, $P < 0.001$). There was variable quality of studies, with 33.3% being classified as 'strong'.

Conclusion: RT has a positive impact on indicators of FMS in youth but more high-quality studies should be conducted to further investigate the role RT may play in the development of FMS. Additionally, to more comprehensively evaluate the impact of RT on FMS, there is a need for FMS assessments that measure both process- and product-oriented outcomes.

Keywords: Resistance-training, Children, Adolescents, Movement skills, Strength

Key points

- Physical activity guidelines and position statements emphasise the importance of 'activity to strengthen muscle and bone' and research suggests that resistance training might have an impact on fundamental movement skills in youth.

- This meta-analysis found that resistance training has a positive effect on, sprint, squat jump, standing long jump, throw and vertical jump.
- Further research is required to investigate the role resistance training may play in the development of FMS and there should be a focus on both process and product-oriented outcomes.

Background

The positive effects of physical activity on the health and well-being of youth are well established. Appropriate levels of physical activity contribute to the development of healthy musculoskeletal tissues (i.e. bones, muscles and joints), a healthy cardiovascular system (i.e. heart

* Correspondence: h.m.collins@dundee.ac.uk

¹Institute of Sport and Exercise, University of Dundee, Old Hawkhill, Dundee DD14HN, UK

²Moray House School of Education and Sport, University of Edinburgh, Edinburgh, UK

Full list of author information is available at the end of the article

and lungs) and neuromuscular awareness (i.e. coordination and movement control) [1]. They also facilitate maintenance of a healthy body weight, provide various psychological benefits and importantly reduce the risk of several diseases [1].

The current guidelines for children aged 5–18 recommend at least 60 min of daily moderate to vigorous physical activity (MVPA), and minimising the time spent sitting, each day [1, 2]. They also recommend an activity that strengthens muscle and bone, at least 3 days a week [1, 2]. However, despite the guidelines, globally less than 50% of young people are meeting the current physical activity guidelines and physical activity levels demonstrate a decline with age; 25% of 11-year-olds meet the recommendations, compared to just 16% of 15-year-olds [3], which indicates that as children advance to adolescence, physical inactivity (not meeting the recommended 60 min of daily MVPA [1]) becomes ubiquitous.

In offering an explanation for why there may be a decline in physical activity levels, it has been suggested that those who do not enhance their muscular strength and fundamental movement skills (FMS) early in life may not develop in a way that would allow them to participate in a variety of activities and sports with confidence in later life [4]. There is an ambiguity in terminology within the literature used to describe movement skill [5] and therefore based on recommendations [5], FMS can be defined as “an organised series of basic movements that involve a combination of movement patterns of two or more body segments” [6]. FMS are commonly categorised as locomotor (e.g. running, jumping, hopping), stability (e.g. balancing, twisting) and object control (throwing, catching, kicking) [7] which could be described as ‘building blocks’ of more complex movements. In addition, it is important to note that when assessing FMS, product-oriented assessments (such as jump height) and process-oriented assessments (such as movement skills batteries) have been reported in the literature [5]. When assessing FMS as a combination of skills, it is common to see batteries of assessments that are based on the process and quality of movement [8] as well as product-oriented outcomes [9]. The development of process and product outcomes is not necessarily synonymous, and there can be a time lag for an improved process to become autonomous and subsequently translate to the development of the product of the skill [9]. Thus, ideally it is recommended that the assessment of FMS should include both process- and product-oriented measure and therefore provide more of a comprehensive measurement of FMS competence [10].

FMS have been shown to be strongly related to physical activity in childhood and into adulthood. Jaakkola et al., indicated that from early to late adolescence, FMS was a strong predictor of physical activity levels [11].

Supporting this, a systematic review in 2010 [7] reviewed 21 studies which examined FMS competency in children and adolescents and found strong evidence for a positive association with physical activity. Whilst unable to demonstrate causation, these studies suggest that movement competency could play a role in explaining physical activity levels across childhood through to adolescence and adulthood, and that interventions aiming to increase physical activity should target improvements in FMS.

To develop FMS, resistance training may be a favourable intervention strategy. Key organisations (National Strength and Conditioning Association (NSCA), United Kingdom Strength and Conditioning Association (UKSCA), and The British Association of Sport and Exercises Sciences (BASES)) have developed position statements emphasising why youth should be engaged in resistance training and a key benefit identified in these position statements is the positive effect of resistance training on FMS [12–14]. It has been identified that muscular strength is an essential component of motor skill development [15] and both functional (e.g. changes in motor unit coordination) and structural (e.g. muscular hypertrophy) adaptations as a result of resistance training might bring about changes in motor competency [16] which therefore may be linked to the development of FMS. Despite this, the evidence to support the role of resistance training in developing FMS in youth is not well established.

While not specifically focused on FMS, Harries et al. [17] conducted a systematic review and meta-analysis in 2012 which provided evidence for the role of resistance training in improving indicators of FMS via the assessment of product-oriented assessments (vertical jump and sprint). Pooling data from 14 studies, a significant effect of resistance training on vertical jump (mean difference 3.09(95% CI 1.65, 4.51), $Z = 4.23$ ($P < 0.0001$)) was found, suggesting that resistance training has a positive impact on jumping as a movement skill. However, some of the interventions included in this review also involved plyometric training, which is specifically designed to improve power [18] and the focus of the review was on performance gains, i.e. product-oriented measures rather than on the quality of the movement per se. Additionally, all of the participants in this review were athletic adolescents, so this does not provide information regarding younger children or the possible role of resistance training in those who do not take part in organised sport.

There have also been two meta-analyses to date that have investigated the impact of resistance training specifically on athletic performance, in the form of motor skills (running, jumping and throwing) in both children and adolescents [16, 19]. These reviews also had a focus on product-oriented measures and included studies that implemented plyometric training. Behringer et al. [16]

conducted a large meta-analysis of 34 studies with the mean age of all analysed participants being 13.2 ± 3.12 years. A combined mean effect of resistance training was reported for running, jumping and throwing (Hedges' $g = 0.52$, 95% CI 0.33–0.71). Effect sizes for each of the individual aforementioned skill types were Hedges' $g = 0.54$, 95% CI 0.34–0.74, Hedges' $g = 0.53$, 95% CI 0.23–0.83, and Hedges' $g = 0.99$, 95% CI 0.19–1.79 respectively. It was also shown that younger children and non-athletes demonstrated higher gains. This meta-analysis therefore provides evidence that a resistance training intervention could have a positive effect on FMS in youth and importantly, non-athletic participants. Supporting these findings, Lesinski et al. [19] conducted a meta-analysis that included 43 studies with a participant age range of 6–18 years. However, in this study all of the participants were athletes. The analyses using the weighted standardised mean difference revealed moderate effects of resistance training on vertical jump ($SMD_{wm} = 0.80$; $I^2 = 67\%$; $\chi^2 = 137.47$; $df = 46$; $P < 0.001$), and small effects on linear sprint ($SMD_{wm} = 0.58$; $I^2 = 41\%$; $\chi^2 = 55.74$; $df = 33$; $P < 0.01$). The authors concluded that resistance training was effective for improving proxies of physical performance in youth athletes, but with the caveat that most studies were at high risk of bias [19].

In the context of health, there is currently limited review-level evidence to support the isolated impact of resistance training interventions on FMS in non-athletic youth and in particularly limited resistance training studies including process-oriented measures. Therefore, the purpose of this review was to systematically examine the effect of resistance training interventions on fundamental movement skills in youth.

Methods

Search strategy

The search strategy and inclusion criteria were specified and documented in advance on PROSPERO (number CRD42016038365). The conduct and reporting of this review adhered to the guidelines outlined in the PRISMA statement [20].

Electronic literature databases were searched from the year of their inception up to and including June 2017. These were PubMed, MEDLINE, ERIC, PsycINFO, Embase, SPORTDiscus and Scopus. Relevant references from published literature were followed up and included where they met the inclusion criteria and literature not

identified in the electronic searches was sourced. ResearchGate was used to identify research papers written by key researchers in the field. Additionally, these researchers were contacted regarding any literature not yet published, and the authors of this review searched their personal libraries.

The search terms were related to fundamental movement skills, youths and resistance training (see Table 1). The Boolean operator “AND” was used between search categories and the operator “OR” was used within categories. The search strategy was adapted for each database, and searches were logged.

Titles of potentially relevant articles were retrieved using the search strategy, duplicates were removed, and then titles and abstracts were screened by HC. Ten percent ($n = 552$) of the titles and abstracts were screened by SF. The inter-rater reliability for the two reviewers was found to be $\kappa = 0.819$ suggesting a strong level of agreement [21]. Full-text copies were obtained for potentially eligible articles and assessed by HC and SF. During the review of full-text articles, a majority decision was taken in consultation with the other reviewers when disagreements regarding inclusion/exclusion occurred.

Inclusion/exclusion criteria

Studies with participants of school age, between 5 and 18 years were included. No studies were included where the subject group was identified as having a pathological condition or disability which affects movement, such as cerebral palsy or dyspraxia and no studies were included where the subject group was identified as having a behavioural or neuropsychological condition such as autism or attention deficit hyperactivity disorder (ADHD). There may be differential adherence, impact and need for different programmes for groups of children with these identified conditions, so they were excluded from the searches. However, an avenue for future work could be to examine these groups but it was out of the scope of this review.

To allow an isolated review of resistance training, all included studies employed resistance training methods but were excluded if they contained plyometric, vibration or neuromuscular training, or training specifically for rehabilitation purposes. Although these modes of training may also be viewed as forms of resistance training, this review aimed to investigate if isolated strength exercises alone had an effect on FMS. There was no restriction on

Table 1 Systematic review search categories and terms

Youth ^a , young, child ^a , teen ^a , adol ^a , pube ^a , boys, girls	Resistance training, resistance program ^a , resistance intervention, resistance exercise, weight training, strength and conditioning	Movement, motor, skill, locomotor, physical-performance, athletic-performance, object-control, stability, hop, jump, run, sprint, throw, balance, kick
--	---	--

^aSearch term truncated

location (e.g. school-based or sports centre) or timing (e.g. during or after school).

Although studies were included that used a control group and also those that did not, for the purpose of this paper, the analysis focused solely on studies that included a control group, and therefore are referred to as controlled trials (CTs).

It is important to note that although the aim was to include both process- and product-oriented measures of FMS, no studies included process-oriented measures and therefore only product-oriented measures of jump height/force, throw distance/velocity and sprint times were included. There were not sufficient data to include the stability component of FMS in the meta-analysis nor FMS batteries of assessments.

Data extraction

Data were extracted using an electronic form by HC and included study characteristics (e.g. country, year); participant characteristics (e.g. sample size, age, sex); intervention components (e.g. setting, duration, content); and changes in the outcomes (e.g. change in fundamental movement skills). The outcome data were extracted in the form of mean, standard deviation and sample size. To check reliability, a second reviewer carried out data extraction on 10% of the included studies, and any disagreements were resolved through discussion with all authors.

Methodological quality and risk of bias assessment

The “Quality Assessment Tool for Quantitative Studies” developed by the Effective Public Health Practice Project in 1998 [22] was used to assess the quality and risk of bias of the included studies. The results of the assessment led to an overall methodological rating of strong, moderate or weak in eight sections: selection bias, study design, confounders, blinding, data, collection methods, withdrawals and dropouts, intervention integrity and analysis. The assessment tool has been found to be valid and reliable [23]. To check reliability, a second reviewer carried out this assessment on 10% of the included studies, and any disagreements were resolved through discussion between the two reviewers. Overall, the data extraction and risk of bias accuracy of one reviewer was deemed to be acceptable.

Meta-analysis

Random effects meta-analyses were conducted with the Comprehensive Meta-analysis software (version 2.2.064). Hedges’ *g* with randomised effects and 95% CIs were calculated for trials with sufficient data. The effect size calculations compared the effect of the intervention on the intervention group in comparison to the controls. The magnitude of Hedges’ *g* was interpreted using Cohen’s (1988) convention as small (0.2), medium (0.5) and large (0.8) [24]. A significance level of $P \leq 0.05$ was applied.

Heterogeneity was assessed using the I^2 statistic. For interpretation, I^2 values of 25, 50 and 75% were considered to indicate low, moderate and high heterogeneity, respectively [25]. Publication bias was assessed by calculating Egger bias statistics [26] and Rosenthal’s fail-safe *N* [27]. Corresponding funnel plots were created.

A moderator analysis was conducted to determine whether the intervention effects on the outcomes differed by sex of participants (males or females), sex of training group (i.e. the training group was designed for either males, females or mixed sex), sport status (specified sports participants or not), age (< 12 or > 12 years, based on primary and secondary school age split), pubertal stage (<Tanner stage 3 or >Tanner stage 3, based on pre-pubertal/pubertal and pubertal/post-pubertal stages), location (school during physical education (PE), school during free time or community), type of control (no resistance training, normal activity, wait-list) and quality of study (weak, moderate or strong). Additional moderator analyses were planned for ethnicity and supervised compared to self-regulated sessions. However, there was insufficient data to allow these analyses. Although data were also extracted for frequency and duration of interventions, a moderator analysis was not conducted on this data due to the inappropriateness of separating their independent and combined impact on training outcomes.

It is important to note that for outcomes where a decrease in score was a positive intervention effect (e.g. sprint) and an increase in score was a positive effect (e.g. jump) this was accounted for in the analyses to ensure an accurate calculation of effect sizes.

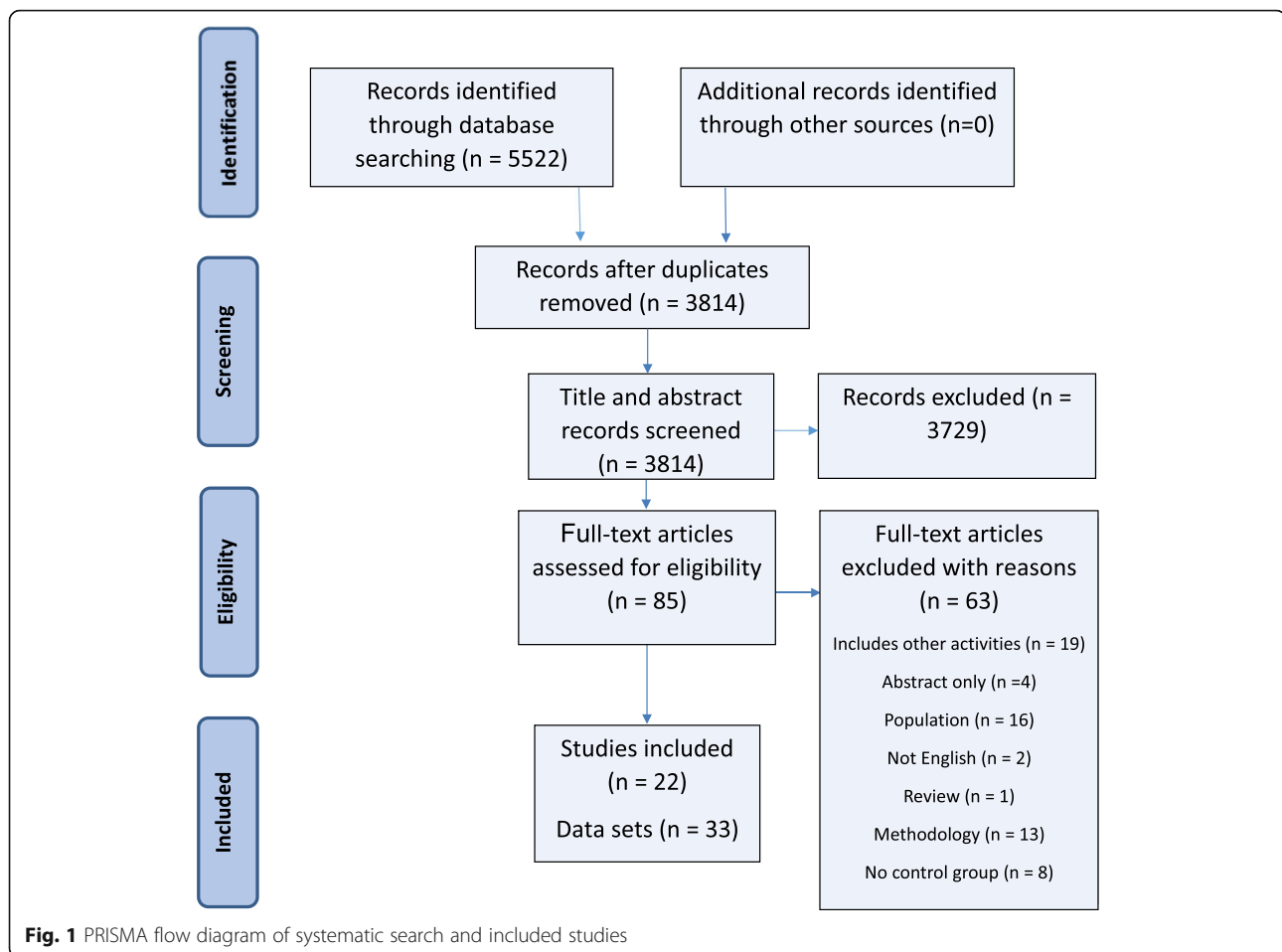
Results

Out of an initial 5522 studies identified through database searches, 85 studies met the inclusion criteria (Fig. 1). Following assessment of the full text, 63 studies were excluded from the meta-analysis as they did not meet the inclusion criteria. Twenty two studies and 33 data sets were included in the meta-analysis (some studies had more than one intervention group).

Study characteristics

Studies were conducted in 11 different countries (Canada, USA, Tunisia, Greece, Spain, Switzerland, Germany, UK, Brazil, Norway and Portugal). There were 542 participants in the experimental groups (sample sizes ranged from 8 to 78 participants) and 401 participants in the control groups (sample sizes ranging from 5 to 76 participants).

The age of all participants ranged from 8 to 17 years. Five outcomes related to fundamental movement skills were included in the analysis: sprint, throw, vertical jump, squat jump and standing long jump. The average attendance figures for the studies that reported it was 89%. The study details can be found in Table 2.



Synthesis of results

For each study, Hedges' g was calculated for each outcome variable to determine an overall intervention effect. Figure 2 illustrates the effect sizes for all of the studies and the overall effect size for each outcome, which ranged from 0.292 to 0.730, indicating a small to medium intervention effect relative to controls. Significant intervention effects were identified for all outcomes. These were sprint (Hedges' $g = 0.292$, 95% CI 0.017 to 0.567, $P = 0.038$), squat jump (Hedges' $g = 0.730$, 95% CI 0.374 to 1.085, $P = 0.000$), standing long jump (Hedges' $g = 0.298$, 95% CI 0.096 to 0.499, $P = 0.004$), throw (Hedges' $g = 0.405$, 95% CI 0.094 to 0.717, $P = 0.011$) and vertical jump (Hedges' $g = 0.407$, 95% CI 0.251 to 0.564, $P = < 0.001$). Overall effect sizes for outcomes were in favour of the intervention.

Based on the thresholds [25] moderate heterogeneity was identified for squat jump ($I^2 = 59\%$) and low heterogeneity for all other outcomes ($I^2 = 0-35\%$).

Publication bias

To identify possible publication bias, effect sizes were plotted against standard errors to give funnel plots as

illustrated in Fig. 3. This indicated the presence of publication bias which was confirmed by a significant result from Egger's test [26]. Rosenthal's fail-safe N [27] found that 1314 additional studies would be needed for the cumulative effect to be non-significant. Therefore, it can be concluded that there is possible publication bias but that it is unlikely to exert a strong influence.

Quality appraisal

Through the quality assessment process, 33.3% of the studies were classified as 'strong', 33.3% were classified as 'moderate' and 33.3% were classified as 'weak'. Investigating the quality of studies as a moderator, the only significant effect was on sprint (Table 3).

Moderator analysis

Moderator analysis followed to determine whether the intervention effects on each outcome variable differed by sex of participants, sex of the training group, sport status, age, pubertal stage, type of control group activity and the quality score of the studies. The significant findings are shown in Table 3. There was a selected impact of sex, sport status, type of control and quality on some of the

Table 2 Description of included studies/data sets

Study	Country	Participant details				Intervention details				Outcomes included	Quality score		
		N	Age (years ± sd)	Pubertal stage (Tanner)	Sport/not specified	% males	Sex of training group	Location	Weeks/x per week (min per session)			Sets/reps/intensity	Exercises
Alberga et al. (2015) [38]	Canada	EG 78 CG 76	EG 15.9 ± 1.5 CG 15.6 ± 1.3	4–5	Not specified	29	Mixed	Community	26 weeks × 4(60 min)	2–3 sets, 6–15 reps, max for reps	Whole body exercises on resistance machines + some dumbbell exercises and body weight exercises	Vertical jump	2
		EG 11 CG 6	EG 15.9 ± 1.2 CG Not stated	Not stated	Sport	100	Males	Not stated	12 weeks × 3	3–5 sets, 3–20 reps, 60–95% 1RM	Day 1: bench press, power clean, push jerk, leg press, incline, push ups, back extensions abs. Day 2: bench press, power clean, push jerk, lunges, decline, push ups, back extensions, abs. Day 3: bench press, power clean, push jerk, attacker, military press, push ups, back extensions, abs.	Vertical jump	3
Channell et al. (2008) b [39]	USA	EG 10 CG 6	EG 15.9 ± 1.2 CG Not stated	Not stated	Sport	100	Males	Not stated	12 weeks × 3	3–5 sets, 3–20 reps, 60–100% 1RM	Day 1: bench press, squat, deadlift, leg press, incline, push ups, back extensions, abs. Day 2: bench press, squat, deadlift, lunges, decline, push ups, back extensions, abs. Day 3: bench press, squat, deadlift, attacker, military press	Squat jump, vertical jump	3
Chelly et al. (2009) [40]	Tunisia	EG 11 CG 11	EG 17 ± 0.3 CG 17 ± 0.5	5	Sport	100	Males	Community	8 weeks × 2	4 sets, 2–7 reps, 70–90% 1RM	Half back squat	30-m sprint, squat jump, vertical jump	3
Christou et al. (2006) [41]	Greece	EG 9 CG 9	EG 13.8 ± 0.4 CG 13.5 ± 0.5	3–5	Sport	100	Males	Community	16 weeks × 2(45 min)	2–3 sets, 8–15 reps, 55–80% 1RM	Leg press, bench press, leg extension, pec-deck, leg flexion, overhead press, lat pull-downs, calf raise, sit-ups, and upper-lower back extension	Vertical jump, seated medicine ball put	2
Faigenbaum et al. (1993) [42]	USA	EG 14 CG 10	EG 10.8 ± 0.4 CG 9.9 ± 0.4	1–2	Not specified	68	Mixed	Not stated	8 weeks × 2 (35 min)	3 sets, 10–15 reps, 50–100% 1RM	Leg extension, leg curl, overhead press, bicep curl, chest press	Vertical jump	1
Faigenbaum et al. (1996) [43]	USA	EG 15 CG 9	EG 10.8 ± 0.4 CG 10 ± 0.4	1–2	Not specified	73	Mixed	Not stated	8 weeks × 2	2–3 sets, 6 reps, max for reps	Leg extension, leg curl, chest press, overhead press, bicep curl, ab curl, bent knee leg raise	Vertical jump, standing long jump	1
Faigenbaum et al. (2002) a [44]	USA	EG 22 CG 9	EG 10.2 ± 1.4 CG 9.3 ± 1.5	Not stated	Not specified	68	Mixed	Community	8 weeks × 1(60 min)	1 set, 10–15 reps, max for reps	Leg press, leg extension, leg curl, seated chest press, chest crossover, lat pull down, seated row, shoulder press, biceps curl, and triceps extension, ab curl, lower back extension	Vertical jump, standing long jump	1
Faigenbaum et al.	USA	EG	EG 9.7 ±	Not	Not	55	Mixed	Community	8 weeks × 2(60 min)	1 set, 10–15	Leg press, leg extension, leg	Vertical jump,	1

Table 2 Description of included studies/data sets (Continued)

Study	Country	Participant details				Intervention details				Outcomes included	Quality score		
		N	Age (years ± sd)	Pubertal stage (Tanner)	Sport/ not specified	% males	Sex of training group	Location	Weeks/× per week (min per session)			Sets/reps/ intensity	Exercises
(2002) b [44]		20 CG 9	1.4 CG 9.3 ± 1.5	stated	specified				min	reps, max for reps	curl, seated chest press, chest crossover, lat pull down, seated row, shoulder press, biceps curl, and triceps extension, ab curl, lower back extension	standing long jump	
Faigenbaum et al. (2005) a [45]	USA	EG 19 CG 12	EG 10.4 ± 1.5 CG 10.9 ± 0.9	Not stated	Not specified	58	Mixed	Community	8 weeks × 2(40 min)	1 set, 15–20 reps, max for reps	Leg press, squat press, chest press, seated row, overhead press, pulldown, seated dip, ab curl, hip extension	Vertical jump, standing long jump	1
Faigenbaum et al. (2005) b [45]	USA	EG 12 CG 12	EG 10.4 ± 1.2 CG 10.9 ± 0.9	Not stated	Not specified	50	Mixed	Community	8 weeks × 2(40 min)	1 set, 6–10 reps, max for reps	Leg press, squat press, chest press, seated row, overhead press, pulldown, seated dip, ab curl, hip extension	Vertical jump, standing long jump	1
Flanagan et al. (2002) a [46]	USA	EG 8 CG 20	EG 8.8 ± 0.5 CG 8.7 ± 0.5	Not stated	Not specified	48	Mixed	Community	10 weeks × 2(40 min)	1–3 sets, 8–15 reps, max for reps	Squat, bench, pull downs, military press, bicep curls, hamstring curls, tricep pressdown, curl ups	Medicine ball put, standing long jump, shuttle run	2
Flanagan et al. (2002) b [46]	USA	EG 22 CG 20	EG 8.6 ± 0.58 CG 8.7 ± 0.5	Not stated	Not specified	48	Mixed	School -PE	10 weeks × 2(40 min)	Varied-body weight	Sea crawl, crab crawl, turtle walk, inch worm, treadmill (like a crawl)	Medicine ball put, standing long jump, shuttle run	2
Gorostiaga et al. (1999) [32]	Spain	EG 9 CG 9	EG 15.1 ± 0.7 CG 15.1 ± 0.5	5	Sport	100	Males	Not stated	6 weeks × 2(40 min)	4 sets, 3–12 reps, 40–90%1RM	Supine bench press, half squat, knee flexion curl, leg press and pec-deck	Squat jump, vertical jump, throwing velocity	1
Granacher et al. (2011) [47]	Switzerland	EG 14 CG 14	EG 16.7 ± 0.6 CG 16.8 ± 0.7	4–5	Not specified	48	Mixed	School -PE	8 weeks × 2(90 min)	4 sets, 10 reps, 30–40% 1RM	Leg press, leg extension and flexion, calf raise, weight machine for hip abduction/adduction, back squat	Standing long jump, 20-m sprint	2
Hammami et al. (2017) [48]	Tunisia	EG 16 CG 12	EG 16.2 ± 0.6 CG 16.8 ± 0.2	Not stated	Sport	100	Males	Community	8 weeks × 2(45 min)	3–5 sets, 3–8 reps, 70–90%1RM	Back half squat	Vertical jump, squat jump	2
Hetzler et al. (1997) a [49]	Germany	EG 10 CG 10	EG 13.8 ± 0.6 CG 13.9 ± 1.1	3–4	Sport	100	Males	Community	12 weeks × 3	1–3 sets, 10–12 reps, up to 100% 10RM	Supine bench press, wide grip cable pull down, leg extension, leg curl, leg press, bicep curl, tricep extension, shoulder dumbbell routine, wrist curls, reverse wrist curls	Vertical jump	3
Hetzler et al. (1997) b [49]	Germany	EG 10 CG 10	EG 13.2 ± 0.9 CG 13.9 ± 1.1	3–4	Sport	100	Males	Community	12 weeks × 3	1–3 sets, 10–12 reps, up to 100% 10RM	Supine bench press, wide grip cable pull down, leg extension, leg curl, leg press, bicep curl, tricep extension, shoulder dumbbell routine, wrist curls, reverse wrist curls	Vertical jump	3

Table 2 Description of included studies/data sets (Continued)

Study	Country	Participant details				Intervention details				Exercises	Outcomes included	Quality score
		N	Age (years $\pm$ sd)	Pubertal stage (Tanner)	Sport/ not specified	% males	Sex of training group	Location	Weeks/ $\times$ per week (min per session)	Sets/reps/ intensity		
Lillegaard et al. (1997) a [50]	USA	EG 20 CG 18	EG 11.2 $\pm$ 1.1 CG 10.1 $\pm$ 1.6	1–2	Not specified	100	Mixed	Not stated	12 weeks $\times$ 3 (60 min)	3 sets, 10 reps, 10RM	Vertical jump, shuttle run, 30-yard sprint, standing long jump	3
Lillegaard et al. (1997) b [50]	USA	EG 16 CG 10	EG 14 $\pm$ 0.98 CG 13.1 $\pm$ 1.6	3–5	Not specified	100	Mixed	Not stated	12 weeks $\times$ 3 (60 min)	3 sets, 10 reps, 10RM	Vertical jump, shuttle run, 30-yard sprint, standing long jump	3
Lillegaard et al. (1997) c [50]	USA	EG 8 CG 6	EG 9.5 $\pm$ 1.4 CG 9.6 $\pm$ 1.2	1–2	Not specified	0	Mixed	Not stated	12 weeks $\times$ 3 (60 min)	3 sets, 10 reps, 10RM	Vertical jump, shuttle run, 30-yard sprint, standing long jump	3
Lillegaard et al. (1997) d [50]	USA	EG 8 CG 5	EG 12.6 $\pm$ 1.6 CG 12.6 $\pm$ 1.6	3–5	Not specified	0	Mixed	Not stated	12 weeks $\times$ 3 (60 min)	3 sets, 10 reps, 10RM	Vertical jump, shuttle run, 30-yard sprint, standing long jump	3
Lloyd et al. (2016) a [51]	UK	EG 10 CG 10	EG 12.6 $\pm$ 0.3 CG 12.8 $\pm$ 0.2	Not stated	Not specified	100	Males	School - PE	6 weeks $\times$ 2 (60 min)	3 sets 10 reps, 10RM	20-m sprint, squat jump	3
Lloyd et al. (2016) b [51]	UK	EG 10 CG 10	EG 16.3 $\pm$ 0.3 CG 16.2 $\pm$ 0.3	Not stated	Not specified	100	Males	School - PE	6 weeks $\times$ 2 (60 min)	3 sets 10 reps, 10RM	20-sprint, squat jump	3
Moraes et al. (2013) a [52]	Brazil	EG 14 CG 10	EG 15.5 $\pm$ 0.9 CG 15.6 $\pm$ 0.9	3–4	Not specified	100	Males	Community	12 weeks $\times$ 3	3 sets, 10–12 reps, max for reps	Vertical jump, standing long jump	1
Moraes et al. (2013) b [52]	Brazil	EG 14 CG 10	EG 15.4 $\pm$ 1.1 CG 15.6 $\pm$ 0.9	3–4	Not specified	100	Males	Community	12 weeks $\times$ 3	3 sets, 3–20 reps, max for reps	Vertical jump, standing long jump	1
Negra et al. (2016) [28]	Tunisia	EG 13 CG 11	EG 12.8 $\pm$ 0.3 CG 12.7 $\pm$ 0.2	1–3	Sport	100	Males	Community	12 weeks $\times$ 3 (90 min)	4 sets, 8–12 reps, 40–60% 1RM	Vertical jump, standing long jump, squat jump, 30-m spring, <i>t</i> test	1
Saeterbakken et al. (2010) [33]	Norway	EG 14 CG 10	EG 16.6 $\pm$ 3.1 CG 16.5 $\pm$ 3.9	Not stated	Sport	0	Females	Community	6 weeks $\times$ 2 (75 min)	4 sets, 406 reps, max for reps	Throwing velocity	1

Table 2 Description of included studies/data sets (Continued)

Study	Country	Participant details			Intervention details				Outcomes included	Quality score			
		N	Age (years $\pm$ sd)	Pubertal stage (Tanner)	Sport/ not specified	% males	Sex of training group	Location			Weeks/ $\times$ per week (min per session)	Sets/reps/ intensity	Exercises
Sander et al. (2012) a [53]	Germany	EG 30 CG 25	EG 15 CG 15	Not stated	Sport	100	Males	Community	104 weeks $\times$ 2	5 sets, 4–10 reps, max for reps	Parallel front and back squats, bench presses, deadlifts, neck presses and exercises for the trunk muscles as well as the standing row	30-m sprint	3
Sander et al. (2012) b [53]	Germany	EG 18 CG 33	EG 13 CG 13	Not stated	Sport	100	Males	Community	104 weeks $\times$ 2	5 sets, 4–10 reps, max for reps	Parallel front and back squats, bench presses, deadlifts, neck presses and exercises for the trunk muscles as well as the standing row	30-m sprint	3
Santos et al. (2012) [54]	Portugal	EG 15 CG 10	EG 14.5 $\pm$ 0.6 CG 14.2 $\pm$ 0.4	3–4	Sport	100	Males	Community	10 weeks $\times$ 2	3 sets, 3–12 reps, max for reps	Day 1: squat, press, upright row, lunge, push up, bicep curl, tricep dip, abs. Day 2: squat, deadlift, chest fly, front raise, row, calf raise, tricep extension, abs. Day 3: jump, high pull, press, upright row, squat jump, lying press, broad jump, abs	Squat jump, vertical jump, medicine ball throw	2
Weltman et al. (1986) [55]	USA	EG 16 CG 10	EG 8.2 $\pm$ 1.3 CG 8.2 $\pm$ 1.3	> 2	Not specified	100	Males	Community	14 weeks $\times$ 3(45 min)	1 set, 30 s on, 30 s off	Biceps, triceps, bench press, quads, hamstrings, shoulder press, hip abduction/adduction, butterfly, forearm conditioner	Vertical jump, standing long jump	2
Zouita et al. (2016) [29]	Tunisia	EG 26 CG 26	EG 13–14	2–3	Sport	100	Males	Community	12 weeks $\times$ 3(90 min)	15–20 reps, 30–80%1RM	Squat, bench press, push ups, sit ups	30-m sprint, squat jump, vertical jump, t test	2

*EG experimental group, CG control group, rep repetition, max maximum, RM repetition maximum, db abdominal, lat latissimus dorsi

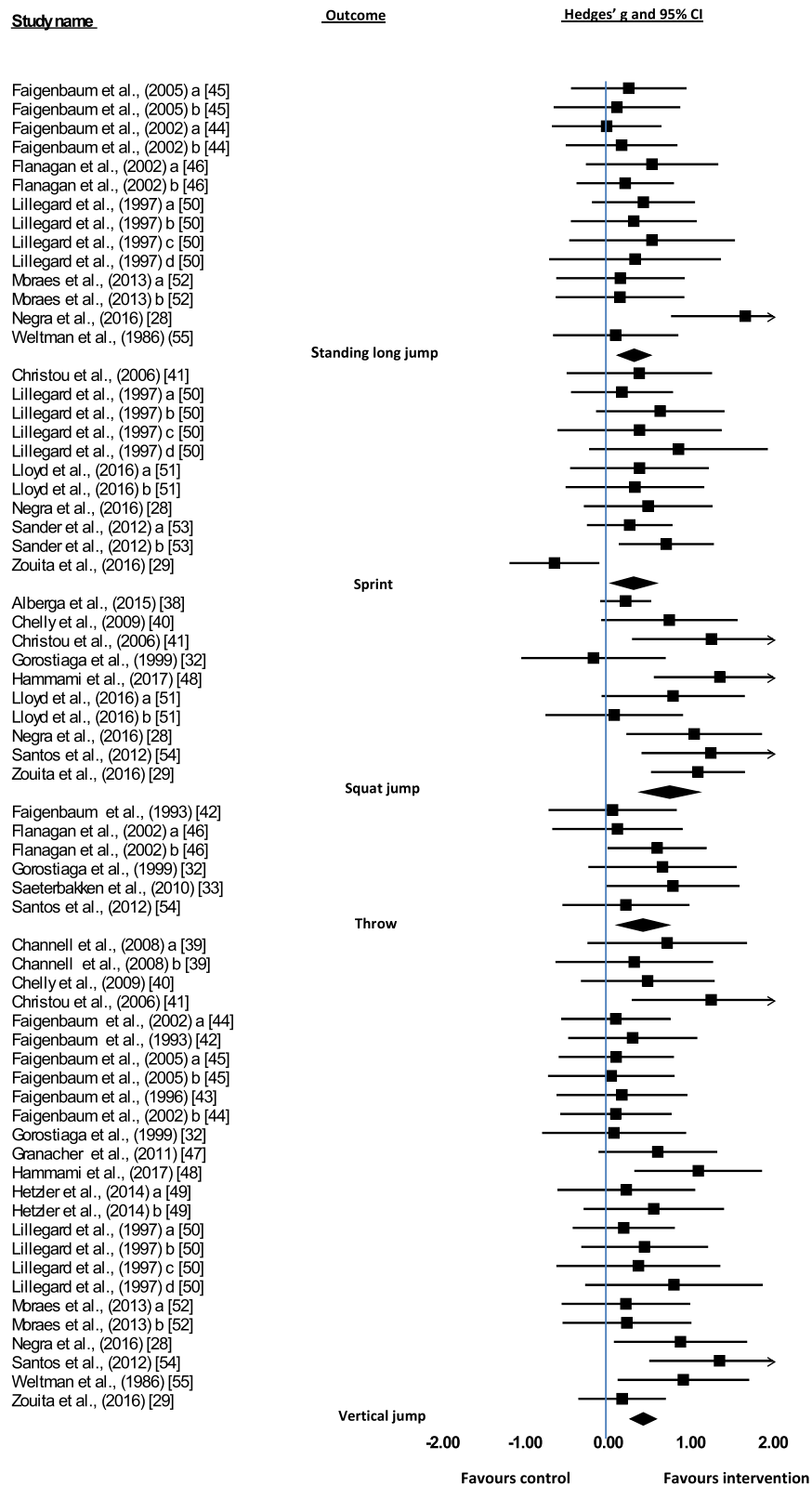


Fig. 2 Summary of all fundamental movement skills meta-analyses

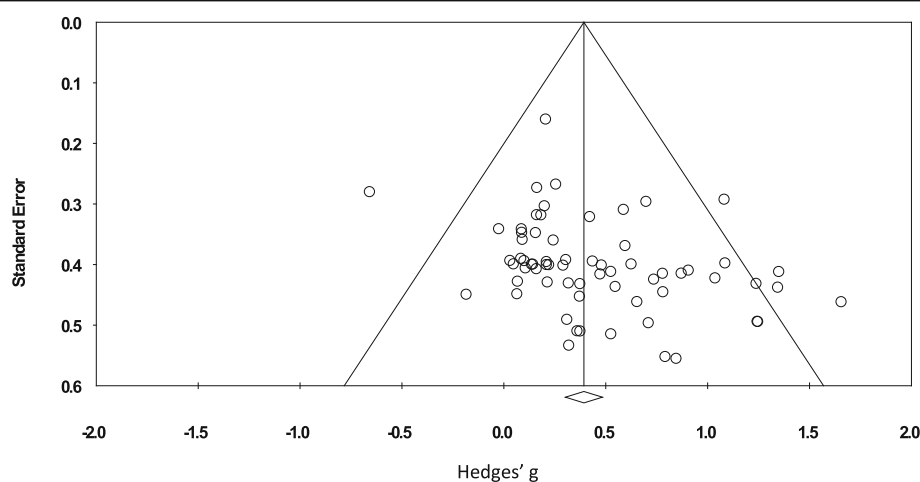


Fig. 3 Funnel plot of publication bias

outcomes, most commonly on squat and long jump. These moderators did not have an impact on all outcomes though. Age and pubertal status were not found to statistically moderate the impact of interventions on any of the outcomes examined. However, it should be noted that there were not equal numbers of studies in all comparisons, which may have had an impact on the findings.

Discussion

Summary of evidence

The UKSCA [13] and NSCA's [12] position statements on youth resistance training both suggest that resistance training may have a positive impact on fundamental movement skills. This is the first meta-analysis reported that focusses solely on resistance training, with the aim of examining the impact of resistance training on fundamental movement

skills in youth. Analysis indicated that resistance training has a positive impact on a number of fundamental movement skills as assessed by product-oriented measurement outcomes. Statistically significant effect sizes were found for all of the FMS outcomes included a medium effect of resistance training interventions on squat jump and a small effect on all other outcomes (vertical jump, standing long jump, sprint and throw).

It has been identified that muscular strength is an essential component of motor skill development [15] and both functional (e.g., changes in motor unit coordination) and structural (e.g., muscular hypertrophy) adaptations as a result of resistance training might bring about changes in motor competency [16] which therefore may be linked to the development of FMS. In particular, neural adaptations as a result of resistance training include changes in motor

Table 3 Moderator analysis

Moderator	Outcome	Hedges'g (95% CI)	No. of studies	Between group comparison: Q (df)
Sex of participants	Squat jump	Males 0.836** (0.497–1.175)	9	7.080 (1)**
		Females 0.207 (–0.108–0.522)	1	
Sex of training group	Squat jump	Males 0.836** (0.497–1.175)	9	7.080 (1)**
		Mixed 0.207 (–0.108–0.522)	1	
Sport status	Squat jump	Sport 0.949*** (0.585–1.759)	7	8.891 (1)**
		Not sport 0.251 (–0.029–0.530)	3	
	Standing long jump	Sport 1.658 *** (0.752–2.564)	1	9.107 (1) **
		Not sport 0.227* (0.020–0.433)	13	
Type of control	Standing long jump	No strength 0.227*(0.020–0.433)	13	9.107 (1)**
		Sport only 1.658** (0.752–2.564)	1	
Quality score	Sprint	1 (strong) = 0.481 (–0.306–1.268)	1	12.575 (2)**
		2 (moderate) = –0.657*(–1.207–0.107)	1	
		3 (weak) = 0.418** (0.173–0.663)	9	

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

unit coordination, firing and recruitment, which are factors that are known to be essential for optimal movement, and likely to play a major role in reported changes, especially in younger children for whom hypertrophy is less likely [16].

Reinforcing this, it has been reported that increases in sprint performance due to resistance training are most likely caused by increases in neuromuscular activation of the trained muscles [28, 29]. Thus, there appears to be strong evidence from this meta-analysis to support the role of resistance training to enhance outcomes commonly associated with FMS in youth, which might be a logical assumption when strength is reported to be an essential component of motor skill competency [15].

The largest effect size in this meta-analysis was for the squat jump. This meta-analysis included only isolated resistance training interventions, suggesting that these effects occur with resistance training in the absence of any form of power training (such as plyometrics) and therefore this may explain the larger effect on a single squat jump which does not involve a plyometric element (counter movement) in comparison to the vertical jump and standing long jump, which do. In support of this, van Hooren et al. identifies that “In the CMJ, the athlete starts from a standing position and initiates a downward movement, which is immediately followed by an upward movement leading to takeoff. In contrast, during the SJ, the athlete descends into a semi-squat position and holds this position for approximately 3 seconds before takeoff.” [30] Therefore, this clarifies the difference between the two assessment outcomes of squat jump and vertical jump.

Plyometrics as a mode of training is included in previously published reviews and scrutiny of the effect sizes across the studies suggests that inclusion of plyometrics leads to greater enhancement of FMS. Behringer et al. [16] reported a medium effect size for jumping; however, this was both vertical jump and standing long jump combined, and it was not specified whether the vertical jump had a counter movement, or whether the analysis included squat jumps, which do not have a plyometric element. Harries et al. [17] reported a positive effect of resistance training on vertical jump performance (mean difference (MD) = 2.09, 95% CI - 0.01 to 4.20, $Z = 1.95$, $P = 0.05$) and a larger effect for studies that combined plyometric with resistance training (MD = 3.03, 95% CI = 0.83 to 5.24, $Z = 2.69$, $P = 0.007$) or included plyometric training alone (MD 5.47 [1.95, 9.00], $Z = 3.04$ [$P = 0.002$]). Lesinski et al. [19], who also included plyometrics as a training mode, similarly reported a large, significant effect size for vertical jump ($SMD_{wm} = 0.80$; $I^2 = 67\%$; $\chi^2 = 137.47$; $df = 46$; $P < 0.001$) (although again it is not clear whether this included a counter movement, or whether squat jumps were also included in the analysis). Also, whilst Lesinski et al. [19] did exclude uncontrolled

trials, direct comparisons with the present review are not wholly appropriate as several of the studies included in their review involved plyometric training. It is not surprising that plyometric exercise including jumping would result in an improvement in jump performance. However, the results from the current meta-analysis would suggest that the development of strength has a key role to play. This strength development could be associated with the quality and coordination of movement rather than power development alone, which could be more relevant for non-athletic populations by producing better movement and therefore more positive physical activity experiences.

For the current review, it is important to be cautious when drawing conclusions from the jumps data both because of the number of studies (there were 25 vertical jump data sets compared to 10 squat jump and 14 standing long jump data sets) and because of the high heterogeneity across the studies that included the squat jump. The moderator analysis indicates that this may be explained by sex and sport status and is discussed further below.

For the outcome of the sprint, there was a small, significant effect which suggests that adaptations occur that might impact on speed. Supporting this, studies have shown significant correlations between maximal squat strength and sprint performance in youth [18, 31]. Behringer et al. [16] reported an effect size of 0.54 (95% CI 0.34–0.74), which included both shuttle runs and straight sprints and similar results were published by Lesinski et al. [19] ($SMD_{wm} = 0.58$; $I^2 = 41\%$; $\chi^2 = 55.74$; $df = 33$; $P < 0.01$) Taken together, these findings imply that resistance training has a positive impact on sprint performance.

There was a small but significant effect size for throw outcomes; however, Behringer et al. [16] reported a large effect size for throwing 0.99 (95% CI: 0.19–1.79). In the present review, it is important to note that out of the 6 data sets, two included a handball throw [32, 33]. This task is sport specific and therefore the specific technique required to play the sport may have influenced the results.

It should be noted that both the reviews from Behringer et al. [16] and Harries et al. [17] combined controlled trials and uncontrolled trials for the analyses, which has implications for comparing results to the present review. For uncontrolled trials, it is difficult to ascertain if any intervention effects are due to the normal process of growth and maturation. Equally, for the studies that include participants taking part in performance sport, the effect of normal training cannot be controlled for; to investigate intervention effects in youth populations it is critical to include a control group to ensure appropriate interpretation of results.

Given the lack of studies that investigated the role of isolated resistance training in improving FMS using process-oriented assessment batteries, the current

review instead examined individual product oriented FMS outcomes. Nevertheless, we have demonstrated that resistance training has a significant effect on all assessed outcomes, which suggests a positive effect on overall movement. This has positive implications for creating strategies to develop FMS and ultimately encourage a healthier and more active lifestyle.

Moderator analysis

To investigate the findings further, a moderator analysis was completed on all outcomes to identify if any effects could be explained by specific moderator variables. It was found that the sex of participants was a moderator for squat jump, sex of training group was a moderator for squat jump, sport status was a moderator for squat jump and standing long jump, the type of control group was a moderator for the standing long jump, and additionally quality score was a moderator for sprint (see Table 2).

Sex of participants and sex of training group

The outcome of squat jump displayed high heterogeneity. The sex of participants (males or females) and sex of training group (i.e. the training group was designed for either males, females or mixed sex) may explain this variance, with more of an effect on males and the male training groups.

In adolescents, it has been reported that during puberty, sex differences in muscular strength occur with boys demonstrating accelerated gains [34]. However, it has been suggested that there is no clear evidence of any difference in strength between pre-pubescent girls and boys [35]. As this meta-analysis included both children and adolescents, it is difficult to make conclusions based on this data. Additionally, for squat jump there was only one study that included females and nine that included males.

Sport status

For squat jump, and standing long jump distance, there was more of an effect of resistance training on those involved in sport compared to those who were not identified as being involved in a specific sport (e.g. identified as 'school children'). Recent research has found an association between FMS and participation in organised sports [36]. Those study participants who take part in sport may therefore already have well-developed FMS at baseline, greater competency with the resistance training, and therefore would be more susceptible to further gains. Those who do not participate in sport might not display as much competency in their movement at baseline and therefore it could take longer to make observable improvements. However, it is important to note that the 'not sport' group may have included children who take part in sport; it was just not reported in the study as a 'sport' group (e.g. a football team).

Age and pubertal stage

There was no moderator effect of age or pubertal stage on any of the outcomes and although Behringer et al. [16] proposed that younger children may experience a greater effect of resistance training due to the degree of neuromuscular adaptation that occurs, Lesinski et al. [19] reported no difference in the effect between pubertal stages or for chronological age. These previous reviews have examined effects in athlete groups, so taken together, it appears that gains in FMS are likely, irrespective of age and maturity status. Morgan et al. [37] identified that some children (particularly older) may experience a 'ceiling effect' with some FMS measures. However, ceiling effects are less likely to occur with product assessments because there is always the possibility of performing better when the scoring is related to speed, distance or accuracy [37].

Type of control and quality score

There was a large imbalance of studies for type of control group, with 13 studies being 'no strength control' versus only 1 study being 'sport only'. For the quality score, there were nine studies that were 'weak' versus only one study being 'moderate' and only one study being 'strong' and therefore it is not possible to make conclusions based on this data. In particular for the quality score, with only one study being strong, this has implications for interpreting the results as well as suggesting that more quality studies should be undertaken to investigate this topic further.

Strengths and limitations

There were a number of strengths of this review. There should be strong confidence in the main findings given the rigorous review process. Strict inclusion/exclusion criteria resulted in an analysis of 33 data sets that examined the effects of resistance training on FMS in 542 youths from 11 countries. Additionally, it is the first review to have included resistance training only interventions, rather than include interventions that include plyometric training, which may be more relevant for a sporting population who may be aiming to improve performance.

This review builds on previous reviews, but with the inclusion of non-sporting populations. The context of this review was that resistance training might be a worthwhile intervention to help improve FMS in inactive youth; thus the inclusion of non-sporting participants was important. Although the meta-analysis conducted by Behringer et al. [16] also included non-athletes, 7 years later, an update to build on the data is beneficial.

There was high compliance reported in the included studies. For the studies who reported it, compliance was 89%. As well as a strength of the current review, high

compliance adds substance to the potential for resistance training as a viable mode of intervention to improve FMS.

There are also limitations apparent that need to be considered when interpreting the results. There was large variability within the study interventions with regards to participant numbers (ranging from 5 to 78 participants), frequency, duration and programme content. The frequency ranged from 1 to 3 times a week and duration ranged from 6 to 104 weeks. Programmes also involved a mixture of sets and reps with a range of intensities. The forest plot (Fig. 3) also signifies large variation in the individual studies' results. There was also an indication of the presence of publication bias which should be considered when interpreting the results.

A limitation of the moderator analysis was that not all of the studies reported data to enable a thorough investigation, and there were not equal numbers of studies in all comparisons, so limited conclusions can be made based on this additional level of analysis. Evaluating the quality of the papers included, there was found to be a mixture of quality of studies, with only 33.3% of the studies classified as strong.

Finally, all of the studies included used product-oriented, rather than process-oriented, outcomes. Therefore this meta-analysis does not inform us about how the movements are performed. This supports previous research that has concluded that the use of process and product assessments should be used to comprehensively capture levels of movement competency in human movement [9, 10].

Conclusions

We are able to conclude that resistance training is likely to have a positive effect on FMS in untrained youth. Overall, significant intervention effects were identified for all outcomes. These were sprint (Hedges' $g = 0.292$, 95% CI 0.017 to 0.567, $P = 0.038$), squat jump (Hedges' $g = 0.730$, 95% CI 0.374 to 1.085, $P < 0.001$), standing long jump (Hedges' $g = 0.298$, 95% CI 0.096 to 0.499, $P = 0.004$), throw (Hedges' $g = 0.405$, 95% CI 0.094 to 0.717, $P = 0.011$) and vertical jump (Hedges' $g = 0.407$, 95% CI 0.251 to 0.564, $P < 0.001$).

This review provided an overview of the current evidence and therefore has given insight into the potential benefits of such interventions. Although we are able to conclude that resistance training interventions have a positive impact on indicators of FMS, this reflects only a small body of published work.

Based on the findings of this review, and in support of the conclusions of previous reviews, future studies should be designed as randomised controlled trials with large samples and include a treatment group with an isolated resistance training intervention. There should be careful consideration given to appropriate intervention

content and assessment methods. Additionally, in the context of increasing physical activity levels, there is a need for assessments that measure both process and product-oriented outcomes.

With resistance training interventions offering potential benefits for youth with regard to FMS, it is imperative that robust and quality studies should be conducted to further investigate the role resistance training may play in the development of FMS. This could ultimately help inform the development of interventions aiming to increase youth physical activity and improve the health of individuals not only during childhood but as they progress through life.

Abbreviations

BASES: British Association of Sport and Exercise Sciences; NSCA: National Strength and Conditioning Association; PA: Physical activity; RT: Resistance training; UKSCA: United Kingdom Strength and Conditioning Association

Acknowledgements

We would like to thank all authors who responded to our requests for additional information.

Funding

No financial support was received for the conduct of this study or preparation of this manuscript.

Availability of data and materials

After publication, all data necessary to understand and assess the conclusions of the manuscript are available to any reader of *Sports Medicine-Open*.

Authors' contributions

HC, JB, AD and SF all participated in the study design, protocol and registration. HC and SF were responsible for selecting articles for inclusion and conducted the risk of bias assessment. HC and SF were responsible for data extraction. HC and JB contributed to the data analysis. HC drafted the manuscript, and all authors provided critical input and final approval.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Competing interests

All authors, Helen Collins, Josephine N Booth, Audrey Duncan and Samantha Fawcner, declare that they have no competing interests.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details

¹Institute of Sport and Exercise, University of Dundee, Old Hawkhill, Dundee DD14HN, UK. ²Moray House School of Education and Sport, University of Edinburgh, Edinburgh, UK. ³Physical Activity and Health Research Centre, University of Edinburgh, Edinburgh, UK.

Received: 2 November 2018 Accepted: 31 March 2019

Published online: 17 May 2019

References

1. World Health Organization. Global recommendations on physical activity for health. [cited; Available from: <https://www.who.int/dietphysicalactivity/leaflet-physical-activity-recommendations.pdf?ua=1>

2. Chief Medical Office. Physical activity guidelines for children and young people (5–18 years). [cited; Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/213739/dh_128144.pdf
3. World Health Organization Regional Office for Europe. Health Behaviour in School-aged Children survey. 2016.
4. Faigenbaum AD, Myer GD. Exercise deficit disorder in youth: play now or pay later. *Curr Sports Med Rep*. 2012;11(4):196–200.
5. Logan SW, Ross SM, Chee K, Stodden DF, Robinson LE. Fundamental motor skills: a systematic review of terminology. *J Sports Sci*. 2018;36(7):781–96.
6. Gallahue DL, Donnelly FC. Developmental physical education for all children. 4th ed. Champaign, Illinois: Human Kinetics; 2003.
7. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents: review of associated health benefits. *Sports Med*. 2010 Dec 1;40(12):1019–35.
8. Cools W, Martelaer KD, Samaey C, Andries C. Movement skill assessment of typically developing preschool children: a review of seven movement skill assessment tools. *J Sports Sci Med*. 2009;8(2):154–68.
9. Bryant ES, Duncan MJ, Birch SL, James RS. Can fundamental movement skill mastery be increased via a six week physical activity intervention to have positive effects on physical activity and physical self-perception? *Sports*. 2016;4(1):10.
10. Logan SW, Barnett LM, Goodway JD, Stodden DF. Comparison of performance on process- and product-oriented assessments of fundamental motor skills across childhood. *J Sports Sci*. 2017;35(7):634–41.
11. Jaakkola T, Yli-Piipari S, Huotari P, Watt A, Liukkonen J. Fundamental movement skills and physical fitness as predictors of physical activity: a 6-year follow-up study. *Scand J Med Sci Sports*. 2016;26(1):74–81.
12. Faigenbaum A, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res*. 2009; 23(5 Suppl):S60–79.
13. Lloyd RS, Faigenbaum AD, Stone MH, Oliver JL, Jeffreys I, Moody JA, et al. Position statement on youth resistance training: the 2014 international consensus. *Br J Sports Med*. 2014;48(7):498–505.
14. Stratton G, Jones M, Fox KR, Tolfrey K, Harris J, Maffulli N, et al. BASES position statement on guidelines for resistance exercise in young people. *J Sports Sci*. 2004;22(4):383–90.
15. Malina RM. Motor development during infancy and early childhood: overview and suggested directions for research. *Int J Sport Health Sci*. 2004;2:50–66.
16. Behringer M, Heede AV, Matthews M, Mester J. Effects of strength training on motor performance skills in children and adolescents: a meta-analysis. *Pediatr Exerc Sci*. 2011;23(2):186–206.
17. Harries S, Lubans D, Callister R. Resistance training to improve power and sports performance in adolescent athletes: a systematic review and meta-analysis. *J Sci Med Sport*. 2012 December;15:S222.
18. Wang Y-C, Zhang N. Effects of plyometric training on soccer players. *Exp Ther Med*. 2016;12(2):550–4.
19. Lesinski M, Prieske O, Granacher U. Effects and dose-response relationships of resistance training on physical performance in youth athletes: a systematic review and meta-analysis. *Br J Sports Med*. 2016;13:781–95.
20. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097.
21. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)*. 2012;22(3):276–82.
22. Effective Public Health Potentials. Effective Public Health Practice Project. Quality Assessment Tool For Quantitative Studies. [cited; Available from: <https://link.springer.com/content/pdf/bbm%3A978-3-319-17284-2%2F1.pdf>
23. Thomas BH, Ciliska D, Dobbins M, Micucci S. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews Evid-Based Nurs*. 2004;1(3):176–84.
24. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
25. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557–60.
26. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629–34.
27. Rosenthal R. The “file drawer problem” and tolerance for null results. *Psychol Bull*. 1979;86:638–41.
28. Negra Y, Chaabene H, Stöggl T, Hammami M, Chelly MS, Hachana Y. Effectiveness and time-course adaptation of resistance training vs. plyometric training in prepubertal soccer players. *J Sport Health Sci*. 2016:1–8.
29. Zouita S, Zouita ABM, Kebbi W, Dupont G, Abderrahman AB, Salah FZB, et al. Strength training reduces injury rate in elite young soccer players during one season. *J Strength Cond Res*. 2016;30(5):1295–307.
30. Van Hooren B, Zolotarjova J. The difference between countermovement and squat jump performances: a review of underlying mechanisms with practical applications. *J Strength Cond Res*. 2017;31(7):2011–20.
31. Comfort P, Stewart A, Bloom L, Clarkson B. Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *J Strength Cond Res*. 2014;28(1):173–7.
32. Gorostiaga EM, Izquierdo M, Iturralde P, Ruesta M, Ibanez J. Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. *Eur J Appl Physiol Occup Physiol*. 1999;80(5):485–93.
33. Saeterbakken AH, Van Den Tillaar R, Seiler S. Effect of core stability training on throwing velocity in female handball players. *J Strength Cond Res*. 2011;25(3):712–8.
34. Beunen G, Thomis M. Muscular strength development in children and adolescents. *Pediatr Exerc Sci*. 2005;12:174–97.
35. Faigenbaum AD, Milliken LA, Westcott WL. Maximal strength testing in healthy children. *J Strength Cond Res*. 2003;17(1):162–6.
36. Field CS, Temple AV. The relationship between fundamental motor skill proficiency and participation in organized sports and active recreation in middle childhood. *Sports*. 2017;5(2).
37. Morgan PJ, Barnett LM, Cliff DP, Okely AD, Scott HA, Cohen KE, et al. Fundamental movement skill interventions in youth: a systematic review and meta-analysis. *Pediatrics*. 2013;132(5):E1361–E83.
38. Alberg AS, Prud'Homme D, Sigal RJ, Goldfield GS, Hadjiyannakis S, Phillips P, et al. Effects of aerobic training, resistance training, or both on cardiorespiratory and musculoskeletal fitness in adolescents with obesity: the HEARTY trial. *Appl Physiol Nutr Metab*. 2015;41(3):255–65.
39. Channell BT, Barfield JP. Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *J Strength Cond Res*. 2008;22(5):1522–7.
40. Chelly MS, Fathloun M, Cherif N, Amar MB, Tabka Z, Van Praagh E. Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. *J Strength Cond Res*. 2009;23(8):2241–9.
41. Christou M, Smilios I, Sotiropoulos K, Volakis K, Piliandis T, Tokmakidis SP. Effects of resistance training on the physical capacities of adolescent soccer players. *J Strength Cond Res*. 2006;20(4):783–91.
42. Faigenbaum AD, Zaichkowsky LD, Westcott WL, Micheli LJ, Fehlandt AF. The effects of a twice-a-week strength training program on children. *Pediatr Exerc Sci*. 1993;5(4):339–46.
43. Faigenbaum AD, Westcott WL, Micheli LJ, Outerbridge AR, Long CJ, LaRosa-Loud R, et al. The effects of strength training and detraining on children. *J Strength Cond Res*. 1996;10(2):109–14.
44. Faigenbaum AD, Milliken LA, LaRosa LR, Burak BT, Doherty CL, Westcott WL. Comparison of 1 and 2 days per week of strength training in children. *Res Q Exerc Sport*. 2002;73(4):416–24.
45. Faigenbaum AD, Milliken L, Moulton L, Westcott WL. Early muscular fitness adaptations in children in response to two different resistance training regimens. *Pediatr Exerc Sci*. 2005;17(3):237.
46. Flanagan SP, Laubach LL, De Marco GM Jr, Alvarez C, Borchers S, Dressman E, et al. Effects of two different strength training modes on motor performance in children. *Res Q Exerc Sport*. 2002;73(3):340–4.
47. Granacher U, Muehlbauer T, Doerflinger B, Strohmeier R, Gollhofer A. Promoting strength and balance in adolescents during physical education: effects of a short-term resistance training. *J Strength Cond Res*. 2011;25(4):940–9.
48. Hammami M, Negra Y, Shephard RJ, Chelly MS. The effect of standard strength vs. contrast strength training on the development of sprint, agility, repeated change of direction, and jump in junior male soccer players. *J Strength Cond Res*. 2017;31(4):901–12.
49. Hetzler RK, DeRenne C, Buxton BP, Ho KW, Chai DX, Seichi G. Effects of 12 weeks of strength training on anaerobic power in prepubescent male athletes. *J Strength Cond Res*. 1997;11(3):174–81.
50. Lillegard WA, Brown EW, Wilson DJ, Henderson R, Lewis E. Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity. *Pediatr Rehabil*. 1997;1(3):147–57.
51. Lloyd RS, Radnor JM, De Ste Croix MBA, Cronin JB, Oliver JL. Changes in sprint and jump performances after traditional, plyometric, and combined

- resistance training in male youth pre- and post- peak height velocity. *J Strength Cond Res.* 2016;30(5):1239–47.
52. Moraes E, Fleck SJ, Dias MR, Simao R. Effects on strength, power, and flexibility in adolescents of nonperiodized vs. daily nonlinear periodized weight training. *J Strength Cond Res.* 2013;27(12):3310–21.
 53. Sander A, Keiner M, Wirth K, Schmidtbleicher D. Influence of a 2-year strength training programme on power performance in elite youth soccer players. *Eur J Sport Sci.* 2013;13(5):445–51.
 54. Santos AP, Marinho DA, Costa AM, Izquierdo M, Marques MC. The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *J Strength Cond Res.* 2012;26(6):1708–16.
 55. Weltman A, Janney C, Rians CB. The effects of hydraulic resistance strength training in pre-pubertal males. *Med Sci Sports Exerc.* 1986;18(6):629–38.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► [springeropen.com](https://www.springeropen.com)

2.4 The effect of resistance training interventions on 'The Self' in youth: a Systematic Review and Meta-analysis.

SYSTEMATIC REVIEW

Open Access



The Effect of Resistance Training Interventions on 'The Self' in Youth: a Systematic Review and Meta-analysis

Helen Collins^{1,2*} , Josephine N. Booth³, Audrey Duncan², Samantha Fawcner¹ and Ailsa Niven¹

Abstract

Background: There is growing evidence that physical activity (PA) is beneficial for the mental health of young people. One area that has been widely examined is the impact of PA on 'the self', which is a term that encompasses a range of specific and related terms (e.g. self-esteem, self-efficacy, self-perceptions). There is evidence that PA is strongly associated with 'the self' in childhood and beyond. However, the impact of the specific PA of resistance training (RT) is not yet clear. The purpose of this review was to advance knowledge on the potential of RT for enhancing mental health by examining the effect of RT interventions on 'the self' in youth.

Methods: This systematic review followed the PRISMA guidelines (PROSPERO registration number CRD42016038365). Electronic literature databases were searched from the year of their inception to October 2018. The search included English language articles that examined the effect of isolated RT on the broad term of 'the self' in youth, with participants of school age (5–18 years). Data were extracted using an electronic form by one reviewer with 10% conducted by a second reviewer. The 'Quality Assessment Tool for Quantitative Studies' was used to assess the quality and risk of bias and was conducted by two reviewers.

Results: From seven peer-reviewed studies, ten data sets were included exploring seven outcomes related to 'the self' in participants aged between 10 and 16 years. Four of these studies (including seven data sets) were combined in a meta-analysis, with results from the remaining three studies reported separately. Significant intervention effects were identified for resistance training self-efficacy (Hedges' $g = 0.538$, 95% CI 0.254 to 0.822, $P < 0.001$), physical strength (Hedges' $g = 0.289$, 95% CI 0.067 to 0.511, $P = 0.011$), physical self-worth (Hedges' $g = 0.319$, 95% CI 0.114 to 0.523, $P = 0.002$) and global self-worth (Hedges' $g = 0.409$, 95% CI 0.149 to 0.669, $P = 0.002$). Although not statistically significant, the effect sizes for the remaining three outcomes were body attractiveness (Hedges' $g = 0.211$, 95% CI -0.031 to 0.454, $P = 0.087$), physical condition (Hedges' $g = 0.089$, 95% CI -0.238 to 0.417, $P = 0.593$) and sport competence (Hedges' $g = 0.004$, 95% CI -0.218 to 0.225, $P = 0.974$). There was variable quality of studies, with just two studies being classified as 'strong'.

Conclusion: This is the first review to synthesise research on the effects of isolated RT interventions on 'the self'. The findings indicate that RT has a positive impact on some aspects of 'the self' in youth. More high-quality studies should be conducted to further investigate this topic. If validated, this type of intervention could have a positive impact on 'the self' and ultimately improve the health of individuals not only during childhood but as they progress through life.

Keywords: Resistance training, Children, Adolescents, Self, Strength

* Correspondence: h.m.collins@dundee.ac.uk

¹Physical Activity and Health Research Centre, Institute of Sport, Physical Education and Health Sciences, Moray House School of Education and Sport, University of Edinburgh, Edinburgh, UK

²Institute of Sport and Exercise, University of Dundee, Old Hawkhill, Dundee, UK

Full list of author information is available at the end of the article

Key Points

- Physical activity guidelines and position statements emphasise the importance of ‘activity to strengthen muscle and bone’. Furthermore, research suggests that resistance training might have an impact on ‘the self’ in youth.
- Resistance training was found to have a positive effect on resistance training self-efficacy, perceived physical strength, physical self-worth, and global self-worth.
- If validated, this type of intervention, as recommended by the UK and WHO physical activity guidelines, could ultimately have a positive impact on ‘the self’ and improve the health of individuals not only during childhood but as they progress through life.

Background

The positive effects of physical activity (PA) on the health and well-being of youth are well established. The most up to date review of evidence states that appropriate levels of PA contribute to the development of healthy musculoskeletal tissues, a healthy cardiovascular system, and neuromuscular awareness [1]. In addition to the physical benefits, there is growing evidence that PA is beneficial for the mental health of young people, including depression, anxiety and self-esteem [2], and in this respect, one area that has been widely examined is the impact of PA on ‘the self’ [3].

The term ‘the self’ is used in this paper to capture a range of specific terms that, while separate, are related (e.g. self-esteem, self-efficacy, self-perceptions). In this respect, PA researchers have typically defined ‘the self’ as having a multi-dimensional and hierarchical structure. This involves more stable constructs (e.g. self-concept ‘a person’s perception of him or herself’ [4] and self-esteem ‘how an individual feels about their sense of self’ [5]) at the apex of the structure which are influenced by less stable sub-domains (e.g. physical self-perceptions ‘a person’s perceptions of their physical self’ [6]) and further sub-areas (e.g. perceived strength).

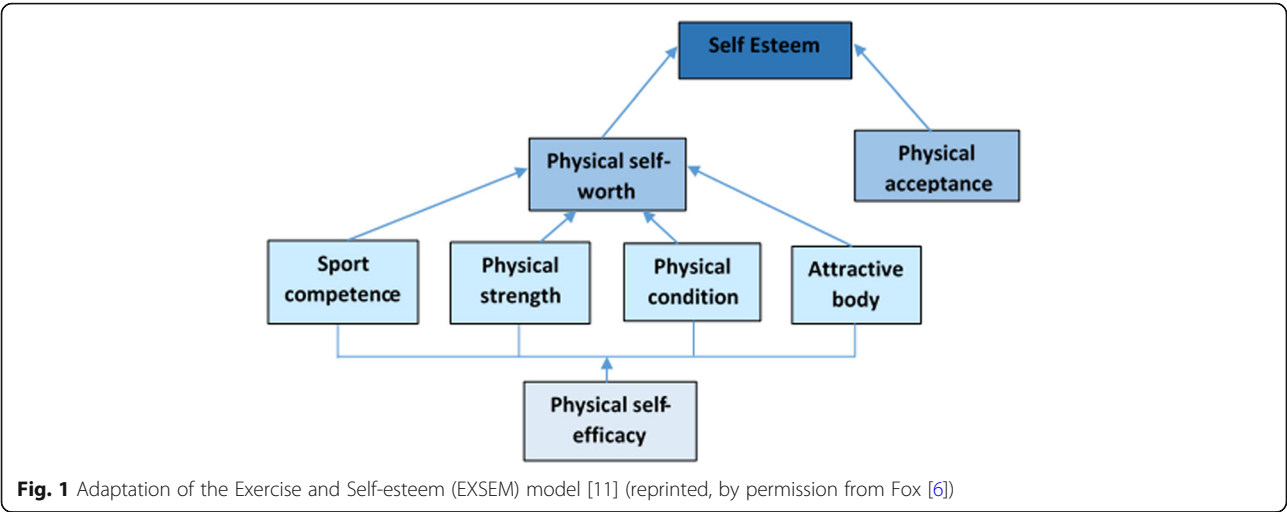
There is review-level evidence that provides support for a positive relationship between PA and constructs relating to ‘the self’ in youth [7–10]. Babic et al. [10] included 64 studies in a meta-analysis and found a significant association between physical activity and physical self-concept and its various sub-domains in children and adolescents. Despite some limitations regarding methodological design, collectively, these reviews provide convincing evidence of the beneficial effects of PA on the ‘the self’.

To explain the mechanism behind the association between PA and ‘the self’, Sonstroem and Morgan [11] proposed the Exercise and Self-esteem Model (EXSEM).

Fox [6] updated the EXSEM model by integrating the Physical Self-perception Profile (PSPP) [12] hierarchical structure (Fig. 1). Within this model, it was proposed that physical responses to exercise (as assessed by physical measures) can influence physical self-efficacy via perceptions of what the body can do (e.g. sport competence, physical strength) and how the body looks (e.g. body attractiveness) [5]. Physical self-efficacy is not a reflective description or evaluation of the self but rather a more situation-specific self-assessment of perceived ability [5]. Within this EXSEM model, Sonstroem and Morgan [11] suggest that self-efficacy expectations regarding particular exercise activities will constitute the most immediate and specific self-perception (i.e. at the bottom of the hierarchy). Self-efficacy is viewed to be the most accurate and most influenced by the environment, and over time, these perceptions can feed forward to influence broader perceptions of physical competence and, ultimately, self-esteem [13].

Supporting the EXSEM model, Lubans et al. [14] presented a recent conceptual model through the process of a systematic review that explored the mechanisms underlying the effect of physical activity on mental health outcomes, including ‘the self’. This model proposes that physical activity has an impact on psychosocial factors (i.e. social connectedness, mood and emotions and physical self-perceptions) which ultimately has an effect on global self-esteem.

In general, the youth PA interventions described in research predominantly focus on the aerobic component of the youth PA guidelines. The PA guidelines however also recommend including activities that strengthen the muscle and bone, on at least 3 days a week [15, 16], and key organisations (National Strength and Conditioning Association (NSCA) [17], United Kingdom Strength and Conditioning Association (UKSCA) [18] and The British Association of Sport and Exercise Sciences (BASES) [19]) have developed position statements emphasising why youth should be engaged in resistance training (RT). RT refers to a specialised method of conditioning whereby an individual is working against a wide range of resistive loads in order to enhance health, fitness and performance [18]. A benefit identified in the position statements is the positive effect of RT on ‘the self’ [17–19]. For example, Lubans et al. [20] investigated whether RT might impact on ‘resistance training (RT) self-efficacy’. This is defined as participants’ confidence and beliefs about RT [20]. In the same way that physical self-efficacy represents an immediate and specific measure of self-efficacy related to physical activities, RT self-efficacy represents an immediate and specific measure of self-efficacy related to RT. RT self-efficacy could be an important factor when considering both the benefits of an RT intervention and adherence to such an intervention.



Despite this positive endorsement of RT in both the PA guidelines and respective position statements, the evidence to support a positive effect of RT on ‘the self’ is inconclusive. Although reviews by Ahn and Fedewa [8] and Liu et al. [9] examining the effect of PA on ‘the self’ in youth included RT interventions, the independent role of RT was not considered. Indirect support for the independent positive effect of RT interventions on the self therefore currently comes from studies that demonstrate a positive association between muscular fitness and physical self-perceptions [21]. Specifically, Lubans and Cliff [22] reported evidence of an association between muscular fitness and physical self-perceptions (perceived physical performance and perceived sports competence), overall physical self-worth and global self-esteem in youth. However, due to the cross-sectional nature of these data, it remains difficult to untangle the direction of the effect.

Thus, although there is evidence of an association between muscular fitness and ‘the self’, it remains unclear whether there is a direct effect of RT on ‘the self’. Indeed, in the BASES position statement, it was argued that there has been limited research on the effects of RT on the psychological well-being of children and adolescents, and 14 years later, the position appears to have changed little [19]. The current review will therefore be the first to examine the isolated effect of RT on ‘the self’. Hence, the purpose of this review was to systematically examine the effect of RT interventions on ‘the self’ in youth.

Methods

The search strategy and inclusion criteria were specified and documented in advance on PROSPERO (number CRD42016038365). The conduct and reporting of this review adhered to the guidelines outlined in the PRISMA statement [23].

Search Strategy

Electronic literature databases were searched from the year of their inception to October 2018. These were PubMed, MEDLINE, ERIC, PsycINFO, Embase, SPORT-Discus and Scopus. Relevant references from published literature were followed up and included where they met the inclusion criteria, and literature not identified in the electronic searches was sourced. This involved the use of ResearchGate to identify research papers written by key researchers in the field. Additionally, these researchers were contacted regarding any literature not yet published and the authors of the present review searched their personal libraries.

The search terms were related to ‘the self’, youths and RT (see Table 1). The Boolean operator ‘AND’ was used between categories, and the operator ‘OR’ was used within categories. The search strategy was adapted for each database, and searches were logged.

Titles of potentially relevant articles were retrieved using the search strategy, duplicates then removed, and then the titles and abstracts were screened by one reviewer (HC). Ten percent ($n = 71$) of the titles and abstracts were screened by a second reviewer (JB). The inter-rater reliability for the two reviewers was found to be Kappa = 1.0 for both the screening and the quality assessment, suggesting a strong level of agreement [24]. Full-text copies were obtained for potentially eligible articles and assessed by two reviewers (HC and JB). During the review of full-text articles, a majority decision was

Table 1 Systematic review categories and search terms

Target population	Resistance training	‘Self’
youth*, young, child*, teen*, adol*, pube*, boys, girls	resistance training, resistance program*, resistance intervention, resistance exercise, weight training, strength and conditioning	self*, competenc*

*Search term truncated

taken in consultation with the other reviewers when disagreements regarding inclusion/exclusion occurred.

Inclusion/Exclusion Criteria

Studies with participants of school age, between 5 and 18 years, were searched for. No studies were included where the subject group was identified as having a pathological condition or disability which affects movement, such as cerebral palsy or dyspraxia, and no studies were included where the subject group was identified as having a behavioural or neuropsychological condition such as autism or attention deficit hyperactivity disorder (ADHD). There may be differential adherence, impact and need for different programmes for groups of children with these identified conditions, so they were excluded from the searches. However, an avenue for future work could be to examine these groups but it was out with the scope of this review.

To allow an isolated review of RT, all included studies employed RT methods but were excluded if they contained plyometric, vibration or neuromuscular training, training specifically for rehabilitation purposes or additional activity (such as an aerobic component or games). Although some of these modes of training may also be viewed as forms of RT, this review aimed to investigate if isolated strength exercises alone had an effect on 'the self', as in particular plyometric training (power-based exercises) and rehabilitation exercises may be more relevant for a sporting population who may be aiming to improve performance. There was no restriction on location (e.g. school based or sports centre) or timing (e.g. during or after school).

Studies were included that used a control group and also those that did not, but all included a pre- and post-intervention measure.

Data Extraction

Data were extracted using an electronic form by one reviewer (HC) and included study characteristics (e.g. country, year), participant characteristics (e.g. sample size, age, sex), intervention components (e.g. setting, duration, content) and changes in the outcomes (e.g. change in questionnaire score). For the participant characteristics, there is a difference between the sex of the training group (i.e. male only, female only or mixed-sex training group) and sex of the participant (male or female). This allows consideration of the impact of (for example) males training in a male-only versus a mixed training group environment. The outcome data were extracted in the form of mean, standard deviation and sample size. To check reliability, a second reviewer (JB) carried out data extraction on the first 10% of the included studies, which were in alphabetical order of the first author. Following this, any disagreements were resolved through discussion with all authors.

Methodological Quality and Risk of Bias Assessment

The 'Quality Assessment Tool for Quantitative Studies' developed by the Effective Public Health Practice Project in 1998 was used to assess the quality and risk of bias of the included studies. The results of the assessment lead to an overall methodological rating of strong (identified as 1), moderate (identified as 2) or weak (identified as 3) in eight sections: selection bias, study design, confounders, blinding, data, collection methods, withdrawals and dropouts, intervention integrity and analysis. The assessment tool has been found to be valid and reliable [25].

To check reliability, JB carried out this assessment on all of the included studies. Following this, any disagreements were resolved through discussion between HC and JB.

Meta-analysis

Random effects meta-analyses were conducted with the Comprehensive Meta-analysis software (version 2.2.064). Hedges' g with randomised effects and 95% CIs were calculated for trials with sufficient data. The magnitude of Hedges' g was interpreted using Cohen's [26] convention as small (0.2), medium (0.5) and large (0.8). A significance level of $P \leq 0.05$ was applied. Heterogeneity was assessed using the I^2 statistic. For interpretation, I^2 values of 25%, 50% and 75% were considered to indicate low, moderate and high heterogeneity, respectively [27]. Publication bias was assessed by calculating Egger bias statistics [28] and Rosenthal's Fail-safe N [29]. Corresponding funnel plots were created.

Moderator Analysis

A moderator analysis was conducted to determine whether the intervention effects on the outcomes differed by sex of participants (males or females), sex of training group (i.e. the training group was designed for either males, females or mixed sex), weight status (healthy weight, overweight/obese, obese or mixed weight status), age (< 12 or > 12 years, based on primary and secondary school age split), pubertal stage ($< \text{Tanner stage 2}$ or $> \text{Tanner stage 2}$, based on pre-pubertal and post-pubertal stages), location (school during physical education (PE), school during free time or community), type of control (no resistance training, nutrition input only, normal activity, PE) and quality of study (weak, moderate or strong). Although data were also extracted for frequency and duration of interventions, a moderator analysis was not conducted on these data due to the inappropriateness of separating their independent and combined impact on training outcomes (e.g. sessions being once a week for 12 weeks versus sessions being twice a week for 6 weeks).

Results

Out of an initial 993 studies identified through database searches after screening titles and abstracts, 16 studies were included (Fig. 2). Out of these 16 studies, nine were excluded from the meta-analysis and review as they did not meet the inclusion criteria. All of the included studies were peer-reviewed journal articles. Three studies met the inclusion criteria but were not included in the overall effect size estimates. This was because one did not provide standard deviations [30] and a further two did not assess outcomes that could be combined with the data from the four studies that were included (self-concept, upper body self-efficacy, lower body self-efficacy and exercise self-efficacy) [31, 32]. However, the findings from these three studies are included in Table 3 and the individual results are discussed. From the four studies that were included in the meta-analysis, seven sets of data were analysed (with some studies having more than one intervention group).

The study details included in the meta-analysis can be found in Table 2, and those not included in the cumulative effect size estimates are reported below and can be found in Table 3. Studies were conducted in three different

countries (USA, Australia and Canada). In total, there were 256 participants in the experimental groups (sample sizes ranged from 13 to 78 participants) and 204 participants in the control groups (sample sizes ranged from 9 to 76 participants). The age of all participants ranged from 10 to 16 years, and only four studies reported Tanner stages (biological age) which ranged from 1 to 5.

The training programmes varied in duration from 8 to 24 weeks (mean 13.4 ± 6.8 weeks) with a mean training frequency of 2.7 ± 0.76 sessions per week (2–4 times a week) and session duration of 53.6 ± 12.1 min (ranging from 45 to 75 min). The average attendance reported by the studies that reported it was 78%. All but one study (which was a circuit-based intervention) included 1–3 sets, with reps ranging from 3 to 15 of a moderate to maximum intensity.

Through the quality assessment process for all of the studies included, two of the studies were classified as ‘strong’, four of the studies were classified as ‘moderate’ and one study was classified as ‘weak’. See Tables 2 and 3 for details.

Meta-analysis

Four studies (including seven data sets) were evaluated in a meta-analysis. Seven outcome variables related to

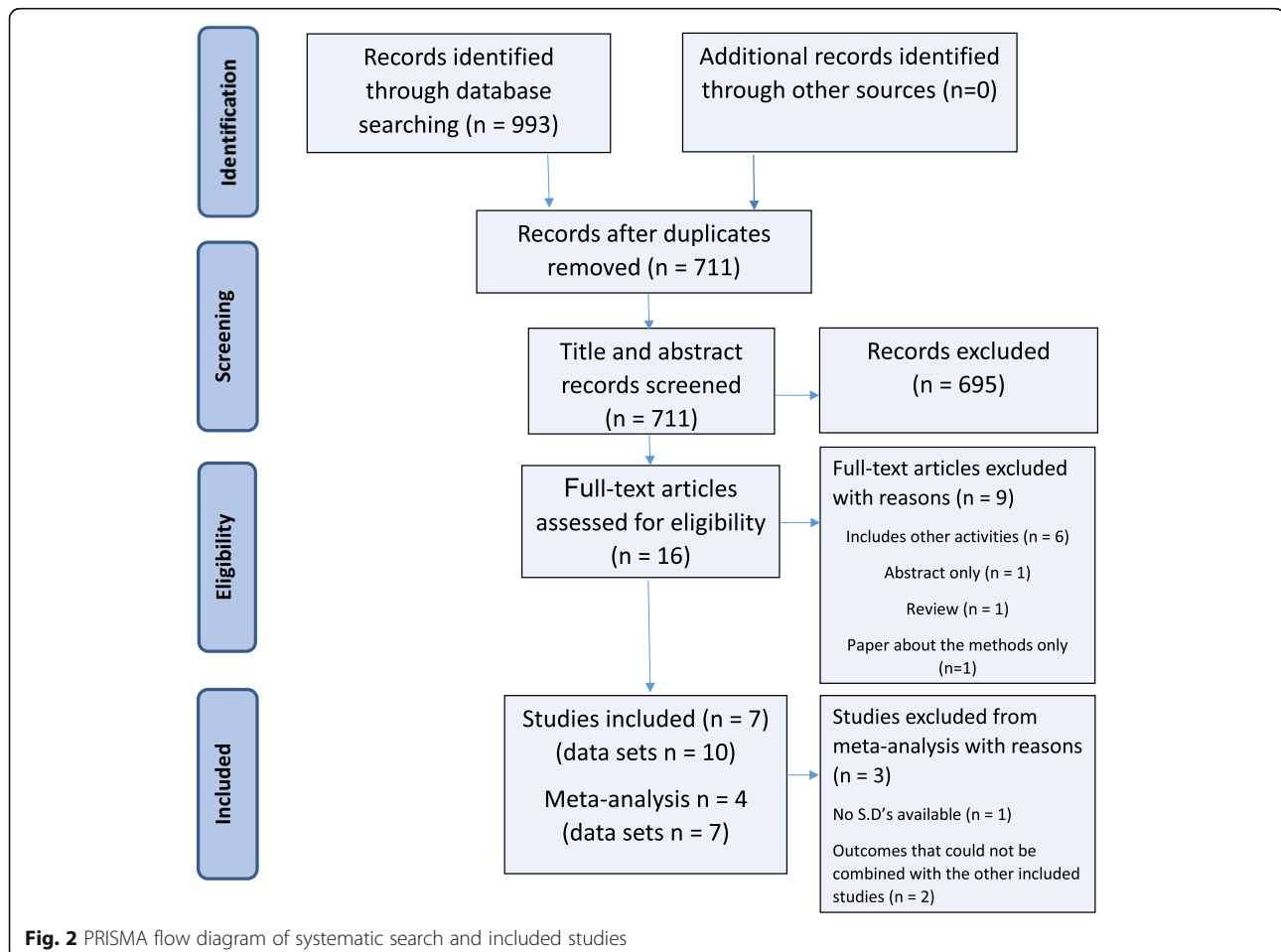


Table 2 Description of included studies/data sets in the meta-analysis

Study	Country	Participant details				Intervention details				Exercises	Assessment tool	Outcomes included	Quality score
		N	Age (years $\pm$ sd)	Pubertal stage (Tanner)	Weight status	% males	Sex of training group	Location	Weeks $\times$ per week (min per session)				
Goldfield et al. [33]	Canada	EG 78, CG 76	EG 15.9 $\pm$ 1.5, CG 15.6 $\pm$ 1.3	4–5	Obese	29%	Mixed	Community	22 weeks $\times$ 4 (45 min)	2–3 sets, 6–15 reps, moderate to max	Physical Self-Perception Profile for Children [34], The Harter Global Self-Esteem sub-scale [35]	Body attractiveness, global self-esteem, physical condition, physical self-worth, physical strength, sport competence	1
Lubans et al. (a) [20]	Australia	EG 22, CG 14	EG 15.3 $\pm$ 0.8, CG 14.8 $\pm$ 0.4	/	Mixed	100%	Mixed	School—free time	8 weeks $\times$ 2 (50 min)	2 sets, 8–12 reps, max for reps	Children's Physical Self-perception Profile [34], an adapted resistance training efficacy scale	Physical self-worth, sport competence, physical condition, body attractiveness, physical strength, RT self-efficacy	2
Lubans et al. (b) [20]	Australia	EG 15, CG 16	EG 14.9 $\pm$ 0.6, CG 14.6 $\pm$ 0.6	/	Mixed	0%	Mixed	School—free time	8 weeks $\times$ 2 (50 min)	2 sets, 8–12 reps, max for reps	Children's Physical Self-perception Profile [34], an adapted resistance training efficacy scale	Physical self-worth, sport competence, physical condition, body attractiveness, physical strength, RT self-efficacy	2
Lubans et al. (c) [20]	Australia	EG 20, CG 14	EG 15 $\pm$ 0.6, CG 14.8 $\pm$ 0.4	/	Mixed	100%	Mixed	School—free time	8 weeks $\times$ 2 (50 min)	2 sets, 8–12 reps, max for reps	Children's Physical Self-perception Profile [34], an adapted resistance training efficacy scale	Physical self-worth, sport competence, physical condition, body attractiveness, physical strength, RT self-efficacy	2
Lubans et al. (d) [20]	Australia	EG 21, CG 16	EG 15 $\pm$ 0.7, CG 14.6 $\pm$ 0.6	/	Mixed	0%	Mixed	School—free time	8 weeks $\times$ 2 (50 min)	2 sets, 8–12 reps, max for reps	Children's Physical Self-perception Profile [34], an adapted resistance training efficacy scale	Physical self-worth, sport competence, physical condition, body attractiveness, physical strength, RT self-efficacy	2

Table 2 Description of included studies/data sets in the meta-analysis (Continued)

Study	Participant details				Intervention details					Assessment tool	Outcomes included	Quality score		
	Country	N	Age (years ± sd)	Pubertal stage (Tanner)	Weight status	% males	Sex of training group	Location	Weeks × per week (min per session)				Sets/reps/intensity	Exercises
Schranz et al. [36]	Australia	EG 30, CG 26	EG 14.9 ± 1.4, CG 15.1 ± 1.6	≥ 2	Overweight/obese	100%	Males	Community	24 weeks × 3 (75 min)	1–3sets, 8–12 reps, to concentric failure	Bench press, leg press, lat pulldown, leg curl (lying or seated), shoulder press (seated), seated row, biceps curl, triceps press-down, calf raise (seated) and abdominal crunch	Exercise Self-efficacy [37] Modified Resistance Training Self-efficacy and Outcome Expectancy Questionnaire [20], Physical Self Worth Scale [38], Self-Perception Profile for Adolescents [39]	Physical self-worth, global self-esteem, exercise self-efficacy, resistance training beliefs, resistance training confidence	1
Velez et al. [40]	USA	EG 13, CG 15	EG 16 ± 0.2, CG /	/	Mixed	53%	Mixed	School—free time	12 weeks × 3(40 min)	2–3 sets, 10–15 reps, 80% of 10 RM, RPE 10	Bench press, seated row, shoulder press, lat pulldowns, flies, bicep curls, and triceps pushdowns or lower body exercises including squats, Romanian dead lift, leg extensions, leg curls, lunges and calf raises	The CY-PSPP [34]	Body attractiveness, global self-esteem, physical condition, physical self-worth, physical strength, sport competence	2

Lubans et al. 'a' indicates male free-weights group, 'b' indicates female free-weights group, 'c' indicates male elastic tubing group, and 'd' indicates female elastic tubing group. "r" indicates no data available
EG experimental group, CG control group, RT resistance training, sd standard deviation, rep repetition, max maximum, RM repetition maximum, RPE rate of perceived exertion, lat latissimus dorsi, CY-PSPP Children and Youth - Physical Self-Perception Profile

Table 3 Studies not included in the cumulative effect size estimates

Study	Country	Participant details				Intervention details				Assessment tool	Outcomes	Quality score		
		N	Age (years ± sd)	Pubertal stage (Tanner)	Weight status	% males	Sex of training group	Location	Weeks × per week (min per session)				Sets/reps/ intensity	Exercises
Faigenbaum et al. [31]	USA	EG 24, CG 9	EG 10.8 ± 0.4, CG 10 ± 0.4	1–2	Healthy	46	Mixed	Community	8 weeks × 2 (60 min)	2–3 sets, 6–8 reps, 6 RM	Leg extension, chest press, leg curl, overhead press, bicep curl	The Martinek Zachkowsky Self-concept Scale for Children [41] Adapted Self-efficacy Scale [42]	Self-concept, self-efficacy upper body, self-efficacy lower body	3
Holloway et al. [30]	USA	EG 13, CG 18	EG 16, CG 16	/	Healthy	0	Females	School—free time	12 weeks × 3 (60 min)	3 sets, 3–10 reps, 65–80% 1 RM	Free weight Olympic-style parallel back squat, bench press, behind-the-neck standing shoulder press, bent-over rows, abdominal crunches	The Physical Self-efficacy Scale [43]	Total self-efficacy, weight training efficacy, physical task efficacy, perceived physical ability, physical self-presentation, physical self-efficacy	2
Mullane et al. [32]	USA	EG 20	EG 10.5 ± 0.5	1	Mixed	90	Mixed	Community	8 weeks × 2 (45 min)	Circuit 60–90s, 6 exercises	Leg press, assisted pull ups, shoulder press, bicep curls, pushups, sit ups	Adapted Children's Self-efficacy Scale [44]	Self-efficacy of exercise	2

“/” indicates no data available

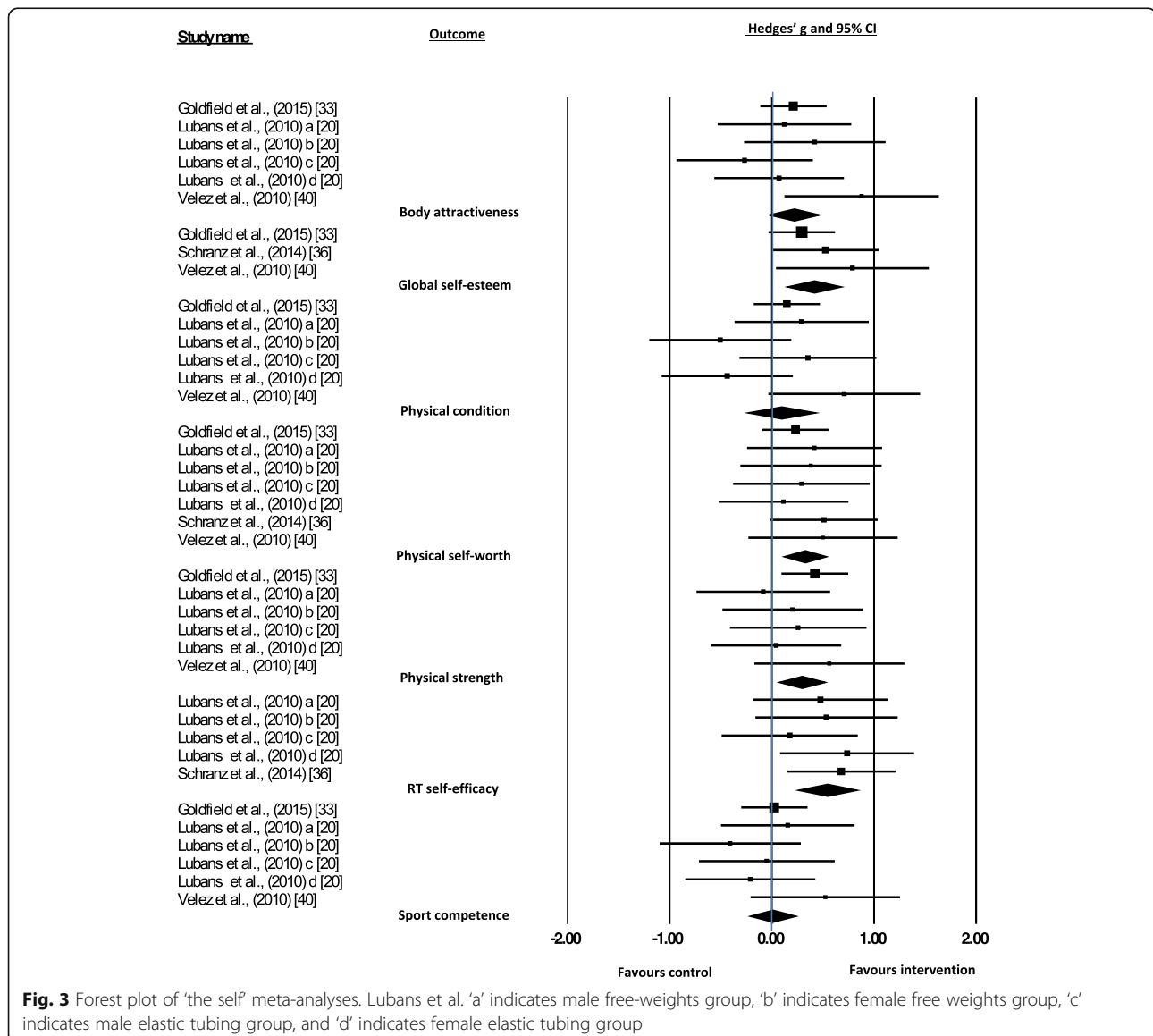
EG experimental group, CG control group, sd standard deviation, rep repetition, max maximum, RM repetition maximum

'the self' were included in the meta-analysis: resistance training self-efficacy, perceived physical strength, physical self-worth, global self-worth, perceived body attractiveness, perceived physical condition and sport competence. Figure 3 illustrates the effect sizes for all of the data sets and the overall effect size for each outcome: resistance training self-efficacy (Hedges' $g = 0.538$, 95% CI 0.254 to 0.822, $P < 0.001$), physical strength (Hedges' $g = 0.289$, 95% CI 0.067 to 0.511, $P = 0.011$), physical self-worth (Hedges' $g = 0.319$, 95% CI 0.114 to 0.523, $P = 0.002$), global self-worth (Hedges' $g = 0.409$, 95% CI 0.149 to 0.669, $P = 0.002$), body attractiveness (Hedges' $g = 0.211$, 95% CI -0.031 to 0.454, $P = 0.087$), physical condition (Hedges' $g = 0.089$, 95% CI -0.238 to 0.417, $P = 0.593$) and sport competence (Hedges' $g = 0.004$, 95% CI -0.218 to 0.225, $P = 0.974$). Significant

effect sizes were observed for resistance training efficacy, physical strength, physical self-worth and global self-worth, and although not significant, there was a small effect size for body attractiveness. There were inconclusive findings for physical condition and sport competence. Based on the thresholds categorised by Higgins and colleagues [27], low to medium heterogeneity was identified for all outcomes (i.e. $I^2 = 0\text{--}44.9\%$) and so moderator analysis was undertaken.

Moderator Analysis

Moderator analysis was conducted to determine whether the intervention effects on each outcome variable differed by sex of participants, sex of the training group, weight status, age, pubertal stage, location, type of control group and the quality score of the studies. There



was a selected impact of sex on perceived physical condition ($Q(df) = 6.994(2)$, $P = 0.030$) with two studies including females (Hedges' $g = -0.469$, 95% CI -0.942 to 0.005 , $P = 0.052$), two studies including males (Hedges' $g = 0.0322$, 95% CI -0.148 to 0.792 , $P = 0.180$) and two studies that were mixed sex (Hedges' $g = 0.323$, 95% CI -0.188 to 0.835 , $P = 0.216$). There were no other significant moderation effects. However, there was a large significant effect size for the one study that included PE as a control group for body attractiveness, although the effect size did not differ statistically from other types of control groups.

Individual Study Results

For the studies that were not included in the meta-analysis, Faigenbaum et al. [31] reported no statistically significant increases in comparison with the control group for the outcomes of self-concept ($P = 0.09$), lower body self-efficacy ($P = 0.69$) and upper body self-efficacy ($P = 0.87$). Holloway et al. [30] included total self-efficacy, weight training efficacy, physical task efficacy, perceived physical ability, physical self-presentation and physical self-efficacy and reported statistically significant increases in all of the outcomes compared to the control group ($P < 0.05$) apart from weight training efficacy ($P = 0.22$), although they did report a significant increase over time for the intervention group ($P = 0.04$). For pre- and post-intervention measures, Mullane et al. [32] reported a statistically significant increase in self-efficacy of exercise over time ($P = 0.008$).

Publication Bias

To identify possible publication bias, effect sizes were plotted against standard errors to yield the funnel plot shown in Fig. 4. This indicated that there was no presence of publication bias and this was confirmed by a non-significant result from Egger's test [28]. Rosenthal's fail-safe N [29] found that 258 additional studies would be needed for the cumulative effect to be non-significant.

Discussion

The UKSCA's and NSCA's position statements on youth RT both suggest that RT may have a positive impact on 'the self' [17, 18]. This is the first meta-analysis to synthesise the existing literature and provide robust initial support for these statements, and the results of this meta-analysis support a positive impact of RT on 'the self' in youth.

In summary, there was a statistically significant medium effect size of RT interventions on resistance training self-efficacy and small significant effect sizes for physical strength, physical self-worth and global self-worth. Although not significant, there was a small effect

size evident for body attractiveness. There were inconclusive findings for the effect on physical condition and sport competence.

Outcomes

To investigate each of the outcomes, starting with resistance training self-efficacy, the meta-analysis suggests a positive intervention effect. This positive association between RT and resistance training self-efficacy was a logical finding based on the nature of the intervention and fits with suggestions based on the EXSEM model [11] that the most immediate and specific aspects of the self are likely to be influenced by targeted interventions. Comparably, for the outcome of perceived physical strength, the meta-analysis indicated a small but significant effect size, which again would be a logical finding given the nature of the intervention.

There were small significant effect sizes evident for physical self-worth and global self-worth. In exploring the possible mechanism behind all of the significant findings, the EXSEM model [11] may provide an explanation. The model (Fig. 1) proposes that perceived physical competencies developed through exercise, including RT, can enhance global self-esteem. This would support the current finding that RT had a positive effect on physical self-worth, physical strength and resistance training efficacy which subsequently may have also had a positive effect on global self-worth. Additionally, the findings of this review are also consistent with the EXSEM model [11], in that the outcomes that correspond most to the intervention (perceived strength, resistance training efficacy and physical self-worth) displayed significant effect sizes. In further support of this, there is previously published review-level evidence that provides support for a positive relationship between PA and constructs relating to 'the self' [7–10]; however, these authors did suggest that because findings varied by methodological design and quality, additional randomised controlled trials should be conducted to replicate and confirm the findings. Isolated RT was also not explored within these reviews.

Furthermore, the conceptual model proposed by Lubans et al. [14] suggests that physical activity has an impact on psychosocial factors (i.e. social connectedness, mood and emotions and physical self-perceptions) which ultimately has an effect on global self-esteem. The findings of the current review support this model with RT having a positive impact on physical self-perceptions which then further impact on the more global measure.

There were additional outcomes that did not display significant effect sizes. When investigating body attractiveness, the meta-analysis showed a small but not significant effect of RT, and the inconsistency in the results of the individual studies may explain this finding as may

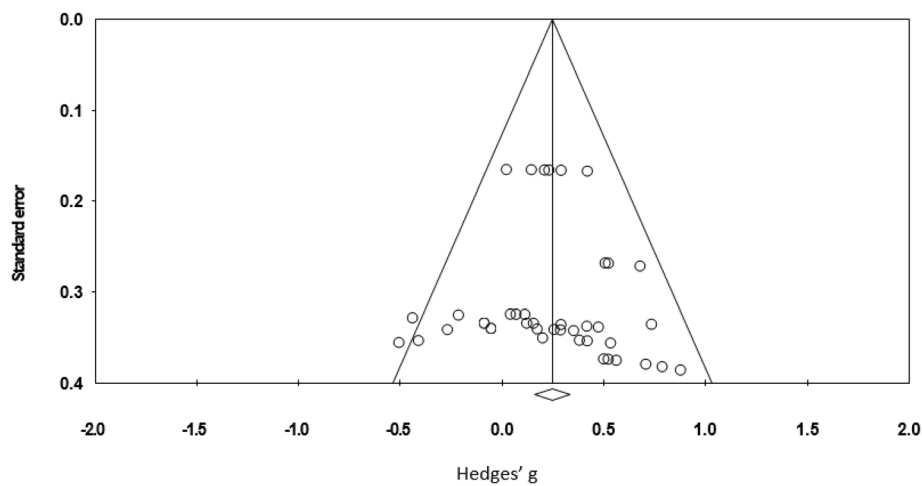


Fig. 4 Funnel plot to show study publication bias

the inclusion of males and females. For example, Lubans et al. [20] found a significant increase in perceived body attractiveness in females, but not in males. For physical condition, the current meta-analysis indicated no conclusive effect of the interventions. This construct is defined as the perceived level of physical conditioning and exercise, and therefore, it may be argued that it reflects aerobic conditioning, and as such, RT might not be expected to exert any influence. Similarly, for sport competence, the meta-analysis does not support a positive effect of the interventions. As the RT content of the studies in this review is not sport specific, this is likely to explain the findings, particularly when the participants are not identified as being involved in organised sport.

From the additional studies that were not included in the meta-analysis, there were findings that support a positive effect of RT on other constructs of 'the self'.

Mullane et al. [32] investigated the impact of RT on exercise self-efficacy and found that there was a significant increase over time based on pre-/post-intervention measures. Holloway et al. [30] explored the effect of resistance training on total self-efficacy, weight training efficacy, physical task efficacy, perceived physical ability, physical self-presentation and physical self-efficacy, and interestingly, the only outcome that did not significantly increase in comparison with the control group was weight training efficacy, which conflicts with findings of the current meta-analysis, but these investigators reported that the groups were not randomly assigned, which may have had an impact on the findings.

Similarly, Faigenbaum et al. [31] examined the effect of RT on self-concept, upper body self-efficacy and lower body self-efficacy and reported no substantial improvement. However, it was identified that this could be due to ceiling effects. Furthermore, these authors

identified a limitation of their study being that the children may not have understood the questionnaire due to their young age (pre-adolescent) [31]. If this is correct, it may be a limitation that is applicable to other studies.

In summary, the evidence suggests that there is a positive effect of RT on specific measures of 'self', but not for the more general measure of self-concept, which in relation to the EXSEM model [11] is a logical finding given that self-concept is the apex of the hierarchy, therefore more stable and less likely to change.

Moderator Analysis

To investigate the findings further, a moderator analysis was completed on all outcomes to identify if any effects could be explained by specific moderator variables. Sex was the only significant moderator intervention effect. Of note, resistance training intervention effects on perceived physical condition were significantly larger in boys compared to girls and mixed-sex groups. There is no explanation offered in the individual studies included in this analysis regarding male and female differences in this context. However, with perceived physical condition relating to aerobic conditioning, it might not be expected to improve due to the nature of the intervention. Thus, the finding for males is surprising, although Hayes et al. [45] reported that males had significantly higher levels of physical self-perceptions than females. It should be noted that there was also a large significant effect size for the one study that included PE as a control group for body attractiveness, but as this was just involving one study, it is difficult to make conclusions based on these data.

It is important to note that there was considerable variability within studies and if there had been a greater number of studies/more equal in comparison that a

robust moderator analysis may have been possible. Additionally, although we did not include duration or frequency in the moderator analysis, it should be noted that there was a wide range of duration, with two studies including an intervention of over 20 weeks [33, 36]. These studies did report significant effects, but also were the only studies to include only overweight/obese participants, which may also have had an impact on the findings.

Although the intervention content described by the included studies is in line with the recommendations from the NSCA and the UKSCA [17, 18], there was still considerable disparity between participant numbers and the intervention content of the studies. It is not possible to indicate whether effects were influenced by training frequency, volume or intensity or study duration, but it is likely that these would be influential and this should be considered in future research.

Although the moderator analysis did not suggest this, the variability between studies could also be accounted for by the mixed weight status of participants since the current meta-analysis included overweight and obese participants. There have been findings to suggest that those who are overweight or obese may have lower baseline 'self' values than their healthy weight counterparts [46] and therefore less chance of ceiling effects. Contrary to this, overweight pre-adolescents may also have higher perceived strength than their healthy weight peers [47]. Therefore, there are implications of the possible impact RT could have on 'the self' specifically in an overweight/obese population. As the current meta-analysis included both healthy weight and overweight/obese participants, this variation based on weight status could have had an effect on the reported outcomes and should be considered when interpreting these results and when designing further studies.

Strengths and Limitations

There were a number of strengths to this review. There should be strong confidence in the main findings given the rigorous review process, including a pre-published protocol. There were a strict inclusion/exclusion criteria which resulted in a review of 7 studies that examined the effects of RT on 'the self' in 460 youths from 3 countries. Despite the small number of studies, this is the first review to investigate the impact of RT on 'the self'. Furthermore, there was low heterogeneity showing that few differences were identified across the studies allowing for appropriate pooling of the data, and additionally, there was no evidence of publication bias so there is less chance of an overoptimistic conclusion.

There was high compliance reported in the included studies (an average of 78% for the four studies that reported it), which is important because it increases

confidence that the effects were due to the intervention. Additionally, good compliance is important given that exercise adherence is critical to positive outcomes [48], adding substance to the potential for RT as a viable mode of intervention to improve outcomes related to 'the self'.

Despite the strengths of the review, there are limitations that need to be considered when interpreting the results. Although there were positive effects reported in this review, there were only a small number of studies included and there were variable findings between the studies making the generalisability of the results difficult. Four of the seven studies included were from the USA, and the seven studies examined varied significantly, including gender, weight status and study design. Additionally, although some of the included studies analysed male and female data separately, some have combined the data. This introduces limitations due to variability in adaptations to RT interventions according to sex [49]. Furthermore, the moderator analysis did not include duration or frequency due to the inappropriateness of separating their independent and combined impacts on training outcomes.

A range of assessment tools was used to measure different parameters of 'the self' which has implications for the validity of the meta-analysis. However, the majority of the studies included used the Children and Youth Physical Self-perception Profile (CY-PSPP) which has been validated as a method of assessing physical self-perceptions in children and youth [50]. Finally, there was a mixture of quality of the studies included, with two of the studies classified as 'strong', four classified as 'moderate' and one classified as 'weak'. More high-quality studies are therefore required to investigate this topic in more depth.

Given the small number of studies analysed, it is difficult to provide practical implications for developing an effective intervention. However, as all of the interventions included in this review were in line with the UKSCA and NSCA recommendations, with the content favouring whole body RT (including elastic bands, free weights, machine weights or body weight) of 1–3 sets and 3–15 reps of moderate to maximum intensity, reference to these position statements for guidance is recommended. Additionally, as there were limited significant findings from the moderator analysis, caution should be exercised over using these results to inform study design.

Conclusions

This review of the literature suggests that RT may have a positive effect on 'the self' in youth, although more high-quality research is required to substantiate this. This meta-analysis provides an overview of the current

research evidence and an insight into the potential benefits of such interventions.

The meta-analysis found a statistically significant, medium effect of RT interventions on resistance training efficacy and small effects on global self-worth, physical self-worth and perceived physical strength. There was a non-significant small effect size for body attractiveness and inconclusive effects on physical condition and sport competence. While we can conclude that RT interventions have a positive impact on 'the self', it is noted that this reflects only a small body of published work.

With RT interventions offering potential benefits for youth with regard to 'the self', it is imperative that more robust and high-quality studies should be conducted to further investigate the role RT may play in the enhancement of 'the self'. The findings of this review support the inclusion of RT when developing PA intervention strategies due to the positive association between 'the self' and PA levels. Based on the findings of this meta-analysis and review, future studies should be designed as randomised controlled trials with large samples and include a treatment group with an isolated RT intervention. There should be careful consideration given for appropriate intervention content and assessment methods. If validated, this type of intervention, as recommended by the UK and WHO PA guidelines, could ultimately have a positive impact on 'the self' and improve the health of individuals not only during childhood but as they progress through life.

Abbreviations

BASES: British Association of Sport and Exercise Sciences; EXSEM: Exercise and Self-esteem Model; NSCA: National Strength and Conditioning Association; PA: Physical activity; PSPP: Physical Self-perceptions Profile; RT: Resistance training; UKSCA: United Kingdom Strength and Conditioning Association

Acknowledgements

We would like to thank all authors who responded to our requests for additional information.

Authors' Contributions

HC, JB, AD and SF all participated in the design, protocol and registration of this review. HC and JB were responsible for selecting articles for inclusion and conducted the risk of bias assessment. HC and JB were responsible for data extraction. HC, JB and AN contributed to the data analysis. HC drafted the manuscript, and all authors provided critical input and final approval.

Funding

No financial support was received for the conduct of this review or preparation of this manuscript.

Availability of Data and Materials

After publication, all data necessary to understand and assess the conclusions of the manuscript are available to any reader of *Sports Medicine-Open*.

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

Not applicable

Competing Interests

All authors (Helen Collins, Josephine N Booth, Audrey Duncan, Samantha Fawcner and Ailsa Niven) declare that they have no competing interests.

Author details

¹Physical Activity and Health Research Centre, Institute of Sport, Physical Education and Health Sciences, Moray House School of Education and Sport, University of Edinburgh, Edinburgh, UK. ²Institute of Sport and Exercise, University of Dundee, Old Hawkhill, Dundee, UK. ³Institute of Education, Community and Society, Moray House School of Education and Sport, University of Edinburgh, Edinburgh, UK.

Received: 1 February 2019 Accepted: 25 June 2019

Published online: 03 July 2019

References

1. Services DoHaH. Physical Activity Guidelines Advisory Committee Scientific Report. 2018.
2. Dale LP, Vanderloo L, Moore S, Faulkner G. Physical activity and depression, anxiety, and self-esteem in children and youth: an umbrella systematic review. In Press. *Ment Health Phys Act*. 2019.
3. Biddle S, Ciacconi S, Thomas G, Vergeer I. Physical activity and mental health in children and adolescents: an updated review of reviews and an analysis of causality. *Psychol Sport Exerc* [cited 2018; In Press.]. Available from: <https://doi.org/10.1016/j.psychsport.2018.08.011>. Accessed 1 July 2019.
4. Shavelson RJ, Hubner JJ, Stanton GC. Self-Concept: Validation of construct interpretations. *Rev Educ Res*. 1976 2018/10/09;46(3):407–41.
5. Sabiston CM, Gilchrist JD, Brunet J. Self-perception in sport and exercise. In: Horn TS, Smith AL, editors. *Advances in Sport and Exercise Psychology*. Leeds: Human Kinetics; 2019. p. 57–74.
6. Fox KR. Advances in the measurement of the physical self. In: Duda J, editor. *Advances in sport and exercise psychology measurement*. Morgantown: Fitness Information Technology; 1998. p. 295–310.
7. Ekeland E, Heian F, Hagen K, Coren E. Can exercise improve self esteem in children and young people? A systematic review of randomised controlled trials. *Br J Sports Med*. 2005;39(11):792–8.
8. Ahn S, Fedewa AL. A Meta-analysis of the relationship between children's physical activity and mental health. *J Pediatr Psychol*. 2011;36(4):385–97.
9. Liu M, Wu L, Ming Q. How does physical activity intervention improve self-esteem and self-concept in children and adolescents? Evidence from a meta-analysis. *PLOS ONE*. 2015;10(8):e0134804.
10. Babic MJ, Morgan PJ, Plotnikoff RC, Lonsdale C, White RL, Lubans DR. Physical activity and physical self-concept in youth: systematic review and meta-analysis. *Sports Med*. 2014;44(11):1589–601.
11. Sonstroem RJ, Morgan WP. Exercise and self-esteem: rationale and model. *Med Sci Sports Exerc*. 1989;21(3):329–37.
12. Fox KR, Corbin CB. The physical self-perception profile: development and preliminary validation. *J Sport Exerc Psychol*. 1989;11:408–30.
13. Schranz N, Tomkinson G, Olds T. What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A systematic review and meta-analysis. *Sports Med*. 2013 Sep;43(9):893–907.
14. Lubans D, Richards J, Hillman C, Faulkner G, Beauchamp M, Nilsson M, et al. Physical activity for cognitive and mental health in youth: a systematic review of mechanisms. *Pediatrics*. 2016 Sep;138(3):1–13.
15. World Health Organization. Global recommendations on physical activity for health. [cited; Available from: <https://www.who.int/dietphysicalactivity/leaflet-physical-activity-recommendations.pdf?ua=1>. Accessed 1 July 2019.
16. Chief Medical Office. Physical activity guidelines for children and young people (5–18 years). [cited; Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/213739/dh_128144.pdf. Accessed 1 July 2019.
17. Faigenbaum A, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res*. 2009; 23(5 Suppl):S60–79.
18. Lloyd RS, Faigenbaum AD, Stone MH, Oliver JL, Jeffreys I, Moody JA, et al. Position statement on youth resistance training: the 2014 International Consensus. *Br J Sports Med*. 2014;48(7):498–505.

19. Stratton G, Jones M, Fox KR, Tolfrey K, Harris J, Maffulli N, et al. BASES position statement on guidelines for resistance exercise in young people. *J Sports Sci*. 2004;22(4):383–90.
20. Lubans DR, Aguiar EJ, Callister R. The effects of free weights and elastic tubing resistance training on physical self-perception in adolescents. *Psychol Sport Exerc*. 2010;11(6):497–504.
21. Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med*. 2014;44(9):1209–23.
22. Lubans DR, Cliff DP. Muscular fitness, body composition and physical self-perception in adolescents. *J Sci Med Sport*. 2011;14(3):216–21.
23. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097.
24. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)*. 2012;22(3):276–82.
25. Thomas BH, Ciliska D, Dobbins M, Micucci S. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews Evid Based Nurs*. 2004;1(3):176–84.
26. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale: Lawrence Earlbaum Associates; 1988.
27. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557–60.
28. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629–34.
29. Rosenthal R. The "file drawer problem" and tolerance for null results. *Psychol Bull*. 1979;86:638–41.
30. Holloway JB, Beuter A, Duda JL. Self-efficacy and training for strength in adolescent girls. *J Appl Spc Psychol*. 1988;18(8):699–719.
31. Faigenbaum A, Zaichkowsky LD. Psychological effects of strength training on children. *J Sport Behav*. 1997;20(2):164.
32. Mullane SL, Bocchicchio VB, Crespo NC. Feasibility and parental acceptability of an 8-week, slow-speed, high-intensity, community-based resistance training program for preadolescent children. *Fam Community Health*. 2017; 40(3):183–91.
33. Goldfield GS, Kenny GP, Alberga AS, Prud'homme D, Hadjiyannakis S, Gougeon R, et al. Effects of aerobic training, resistance training, or both on psychological health in adolescents with obesity: the HEARTY randomized controlled trial. *J Consult Clin Psychol*. 2015;83(6):1123–35.
34. Whitehead JR. A study of children's physical self-perceptions using an adapted physical self-perception profile questionnaire. *Pediatr Exerc Sci*. 1995;7(2):132–51.
35. Harter S. Manual for the self-perception profile for children. Denver: University of Denver; 1985.
36. Schranz N, Tomkinson G, Parletta N, Petkov J, Olds T. Can resistance training change the strength, body composition and self-concept of overweight and obese adolescent males? A randomised controlled trial. *Br J Sports Med*. 2014;48(20):1482–8.
37. Nigg CR, Courneya KS. Transtheoretical model: examining adolescent exercise behavior. *J Adolesc Health*. 1998;22(3):214–24.
38. Whitehead J, Corbin C. Effects of fitness test type, teacher and gender on exercise intrinsic motivation and physical self-worth. *J Sch Health*. 1991;61:11–6.
39. Harter S. Manual for the self-perception profile for adolescents. Denver, CO: University of Denver; 1988.
40. Velez A, Golem DL, Arent SM. The impact of a 12-week resistance training program on strength, body composition, and self-concept of Hispanic adolescents. *J Strength Cond Res*. 2010;24(4):1065–73.
41. Martinek T, Zaichkowsky L. Manual for the Martinek-Zaichkowsky self-concept scale for children. . USA: Psychologists and Educators; 1977.
42. Ewart CK, Taylor CB, Reese LB, DeBusk RF. Effects of early postmyocardial infarction exercise testing on self-perception and subsequent physical activity. *Am J Cardiol*. 1983;51(7):1076–80.
43. Ryckman RM, Robbins MA, Thornton B, Cantrell P. Development and validation of a physical self-efficacy scale. *J Pers Soc Psychol*. 1982;42(5): 891–900.
44. Bandura A. Guide for constructing self-efficacy scales. In: Pajares F, Urdan T, editors. Self-efficacy beliefs adolescents. Greenwich: Information Age Publishing; 2006. p. 307–37.
45. Hayes SD, Crocker PRE, Kowalski KC. Gender differences in physical self-perceptions, global self-esteem and physical activity: evaluation of the physical self-perception profile model. *J Sport Behav*. 1999;22(1):1–14.
46. Kornilaki EN. The effect of body-weight and obesity bias on children's self-esteem. *Preschool Prim Educ*. 2015;3(1):3–14.
47. Sung RY, Yu CW, So RC, Lam PK, Hau KT. Self-perception of physical competences in preadolescent overweight Chinese children. *Eur J Clin Nutr*. 2005 Jan;59(1):101–6.
48. Epstein LH, Goldfield GS. Physical activity in the treatment of childhood overweight and obesity: current evidence and research issues. *Med Sci Sports Exerc*. 1999 Nov;31(11 Suppl):S553–9.
49. Moran J, Sandercock G, Ramirez-Campillo R, Clark CCT, Fernandes JFT, Drury B. A meta-analysis of resistance training in female youth: its effect on muscular strength, and shortcomings in the literature. *Sports Med*. 2018 Jul; 48(7):1661–71.
50. Eklund RC, Whitehead JR, Welk GJ. Validity of the children and youth physical self-perception profile: a confirmatory factor analysis. *Res Q Exerc Sport*. 1997;68(3):249–56.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► [springeropen.com](https://www.springeropen.com)

2.5 Summary of findings

The reviews aimed to address three specific research questions:

1. *Do resistance training interventions have an effect on weight status in youth?*
2. *Do resistance training interventions have an effect on fundamental movement skills, in youth?*
3. *Do resistance training interventions have an effect on 'the self' in youth?*

To summarise the findings of the three systematic reviews, there were positive results reported in all three reviews indicating that there is an effect of resistance training on weight status, FMS and 'the self' to some degree. Therefore, the answer to the research questions are yes, in part. From the analysis of the weight status papers, there was a positive but small effect of resistance training on body fat percentage and skinfolds in youth. From the analysis of the FMS papers there were statistically significant effect sizes for all outcomes. Finally, from the analysis of 'the self' papers, resistance training was found to have a positive effect on resistance training self-efficacy, perceived physical strength, physical self-worth and global self-worth. It is interesting to note that out of the studies that reported change in strength, 91% of studies reported a significant increase in strength, which suggests that the RT intervention strategies were beneficial in this respect despite variable design. Additionally, this lends support to the hypothesis that strength could be a mechanism that explains the effect of RT on the specified outcomes and therefore should be a key outcome for future assessment. Overall, from these findings, it is evident that further research would be beneficial to explore the topic of resistance training and correlates of physical activity in youth, particularly as there is not an extensive volume of quality research focussed on the impact of isolated RT.

Specific considerations to acknowledge are that 42% of the studies included participants who were identified as taking part in a specific sport, so at least 42% of participants were active and therefore it would be beneficial to explore further the effects in an inactive population. Furthermore, the FMS studies included product-oriented measures only and therefore it would be recommended to investigate more process-oriented measures which might be more relevant for non-athletic

populations. Additionally, as ‘the self’ review only included 4 studies in the meta-analysis (7 studies in total) it would be beneficial to add to the research in this area. Finally, through the quality appraisal process, just 29% (the self), 33.3% (FMS) and 44% (weight status) of studies classified as ‘strong’. These findings would suggest that it would be beneficial to conduct further high quality research on the impact of resistance training on all three correlates.

Despite encouraging findings, it was noted across all reviews that there was large variability between studies for measurement tools, sample sizes and intervention design so therefore this should be carefully considered in future study design. To inform the design of a pilot study, exploring the detail of the studies included in these reviews regarding recruitment, participants, location, assessment, and intervention content would be a beneficial process and this was considered in the development of a feasibility study, detailed in Chapter 3.

2.5.1 Recent research – an update

Noting that the search strategies for the meta-analyses were conducted in 2017/2018, it was considered beneficial to address any recently published research that might have a bearing on the conclusions of this chapter. It is important to note that these additional papers have not been through the rigorous systematic review process for inclusion, but they do though provide an overview of ongoing research in the area.

2.5.1.1 Weight status

Following an updated search, there were 1872 further results. After reviewing titles and abstracts, there were three relevant systematic reviews published since the one detailed in this thesis (88-90). Two of these reviews focussed on overweight/obese youth, but predominantly investigated comparisons between aerobic exercise and aerobic and strength exercise combined, with minimal inclusion of the impact of isolated RT on weight status (88, 89). Chen *et al.*, included only one study that investigated the impact of RT alone (88). Kelley *et al.*, identified four studies that

investigated the impact of RT alone, but reported that there were insufficient data for pooling, so therefore conclusions were not made (89).

In the third review, Guillem *et al.*, primarily focussed on the impact of RT on blood pressure, but included BMI as a secondary outcome (90). Five studies were included in the analysis and a significant decrease in BMI was reported. It is important to note that the majority of participants were classified as obese, supporting the findings from the moderator analysis conducted in the meta-analysis detailed in this thesis, which identified a significant effect of RT on BMI of obese participants.

To address specific studies that have been conducted since the searches were last completed in 2017, there were five studies identified that investigated the effect of isolated RT on weight status in youth (91-95). Out of these five studies, three focussed on overweight/obese youth (91, 92, 95) and two studies included sport specific populations (93, 94).

In support of the findings regarding BMI detailed in the systematic reviews, in the only study that reported it as an outcome, there was also a significant decrease in BMI in obese participants (95). Regarding body fat, there were reported significant decreases in three out of the four the studies that reported it as an outcome (91-93), however it is important to note that the study conducted by Blagrove *et al.*, involved distance runners, and therefore a change in body fat might not be expected (94). Two of the studies reported a significant increase in lean muscle mass which is inconsistent with the findings of the meta-analysis detailed in this thesis (91, 93). However these studies included adolescent participants and therefore these increases are more likely to occur in comparison to pre-pubertal groups (91, 93).

Overall, these publications provide evidence to suggest that isolated RT could have a positive impact on outcomes associated with weight status, but there is still scope to conduct further research to substantiate this.

2.5.1.2 Fundamental movement skills

Since 2017, there were 1702 further results, and following a review of titles and abstracts, there has been one published systematic review and one umbrella review relevant to the impact of RT on FMS in youth. Although similarly to the meta-analysis detailed in this thesis, the focus was on product-oriented outcomes (96, 97). In assessing the impact of RT on product related outcomes, both Behm *et al.*, and Lesinski *et al.*, reported effects on power and sprint measures, and the magnitude ranged from small to large (96, 97).

To address the specific studies that have been conducted since 2017, nine studies were identified that investigated the impact of RT on FMS (98-106). Overall, there was large variability regarding intervention content. Regarding the results, following a period of RT, there was significant improvements in jump performance in all of the studies that reported it as an outcome (98, 99, 101, 102, 104, 105). Additionally, there was also significant improvements in sprint times reported (99, 105, 106) and these findings are consistent with the findings of the meta-analysis detailed in this thesis. Two studies reported assessments that were more relevant to process-oriented outcomes. These studies reported an improvement in 'resistance training skills' which were identified as an extension of FMS (100) and 'functional movement', which was identified as movement quality (103), both studies using validated methods. These findings are important as they provide evidence that RT can have an impact on quality of movement, which is not something that was evident from the meta-analysis detailed in this thesis and eludes to the improvement of FMS to enhance the health status of youth.

Overall, these publications provide evidence to suggest that isolated RT could have a positive impact on FMS but further research could be conducted to substantiate this, particularly through the inclusion of product- oriented assessments.

2.5.1.3 'The self'

There were 339 further results since the original search. Despite the original lack of research investigating the impact of RT on 'the self' in youth, following a review of

the titles and abstracts, there were no further studies identified. There was one systematic review that investigated PA interventions to treat paediatric obesity that explored self-esteem, and this review included some studies that implemented RT as the mode of PA (107). These studies were already included in the systematic review detailed in this thesis. Overall the conclusion reported an increase in self-esteem following a period of RT, which is in support of the systematic review detailed in this thesis (107). Overall, this suggests that further research would be beneficial to explore this topic further.

In summary, following an updated review of recent publications, there has not been a significant amount of research conducted in the area and what has been published is presenting similar findings to the meta-analyses detailed in this thesis. Therefore, this still supports the requirement for further research to address this topic in more detail.

CHAPTER 3: Feasibility Studies

3.1 Part a

3.1.1 Introduction

Regarding previous research investigating the impact of RT on weight status, FMS and ‘the self’ in youth explored in Chapter 2, there were numerous limitations identified. Rigorous research to address these limitations would help to determine the role that RT can have and therefore, a definitive RCT is required in the future to contribute to the current knowledge base. To inform this, as part of this thesis, a feasibility study and pilot study were planned. When designing research studies, the Medical Research Council (MRC) framework for developing and evaluating complex interventions strongly advises carrying out feasibility and pilot work prior to running a full-scale trial (87). However, there are some inconsistencies in the literature regarding the definition of feasibility and pilot work (108). Eldridge *et al.* stated that a feasibility study asks whether something can be done, should be proceeded with, and if so, how, whereas a pilot study is effectively a small scale study (108). Similarly, Arain *et al.*, identified that feasibility studies do not evaluate the outcomes but estimate parameters that are needed to design a study (such as recruitment and characteristics of outcome measures), though in a pilot study, data may be analysed and could contribute to a larger scale study (109). Therefore, these are the definitions of feasibility and pilot studies that are used in this thesis.

Additionally, recent guidance identified key stages including: reviewing published research evidence, drawing on existing theories, and ‘design and refine the intervention’ emphasising the importance of creativity being part of the development process (110). By considering these recommendations, combined with exploring the specific details of the published studies identified in the previous systematic reviews (Chapter 2, part a, b and c), this provided the necessary information to establish approaches to recruitment, location, participants, assessment and intervention design through feasibility work to subsequently inform a pilot study for a definitive RCT. This chapter therefore first describes the design specifics of previous relevant studies identified in the systematic reviews before describing two sequential feasibility studies in full.

3.1.1.1 Published study design

3.1.1.1.1 Recruitment strategies used in published studies

Seven (of 62) studies included in the systematic reviews in Chapter 2 specified their recruitment strategies. However, as the majority of the studies were school-based, involved targeting specific clinics (for overweight children) or were sports clubs, a recruitment strategy was perhaps not required as participants were readily available to take part. For community-based intervention studies, recruitment via schools (information sent out to parents), information evenings for parents and local advertising had been implemented successfully. Regarding control groups, some studies offered a follow-up RT intervention to provide a benefit for being part of the study, which could be an effective part of a recruitment strategy. With limited information reported in the studies regarding recruitment methods, there is also rationale for trialling additional methods, such as taster sessions.

3.1.1.1.2 Participant details from published studies

There was a large range of sample size (5-129 participants) and power calculations were reported by few studies. Where specific populations were identified (such as overweight participants, a sport specific group, or a school class for example) sample size was determined by the group rather than targeted recruitment. Additional to considering participant numbers to adequately power a study (a power analysis is included in the pilot study, detailed in Chapter 4), there are minimum standards for coach to participant ratio recommended by the NSCA, with 1:10 recommended for lower junior high school (111). To deliver a RT intervention, additional factors to consider that would impact on participant numbers are the space and equipment to ensure a safe environment. In the reviews, the age range of participants was 8-17 years. Only 21 out of 67 studies (31%) included children who were under 12 years old (primary school), despite evidence that resistance training has been found to be beneficial in children as young as six (20). By targeting a younger age group, this might have positive implications for combatting the age-related decline in PA.

Weight status of participants in the studies identified in the review in Chapter 2 was mixed (10 studies), healthy (15 studies), overweight (2 studies), obese (5 studies) and overweight or obese (2 studies). From the moderator analyses it was identified that weight status was a moderator for the measures of BMI and waist circumference, with more of an effect in those who were obese, suggesting there could be benefit in targeting this population. Furthermore, although it was not possible to identify how many of the studies included inactive children (defined as not meeting the physical activity guidelines for MVPA (12)), the participants in 42% of the studies included in the systematic reviews were identified as taking part in specific sports, so as a minimum, 42% would be classified as active. Therefore, with this thesis investigating whether RT could be a successful strategy to improve physical activity levels, an inactive cohort could also be a favourable target for recruitment.

The sex of the training group was variable, with 25 studies including male participants only, four studies including female only participants, and 37 studies including a mixed sex training group. From the moderator analyses, for FMS it was identified that the sex of training group (i.e. the training group was designed for either males, females or mixed sex) and sex of participants (males or females) were moderators for squat jump performance only, with more of an effect on males. However, this was based on nine studies that focussed on males versus just one that focussed on females and ultimately this supports a mixed sex group as an appropriate target recruitment group. Similarly, it was reported that resistance training intervention effects on perceived physical condition were significantly larger in males compared to females and mixed-sex groups. However, with perceived physical condition relating to aerobic conditioning, it might not be expected to improve due to the nature of the intervention. Thus, the finding for males was surprising and ultimately, based on these analyses, it is difficult to make conclusions. Therefore, with the benefits of RT being applicable to males and females and to maximise recruitment potential, it is a feasible and logical option to target both males and females for recruitment.

3.1.1.1.3 Published studies location selection

Overall, 34 interventions were delivered in the community, 13 were delivered at school during free time and 11 were delivered during school time. Although community-based interventions were the most common, from the moderator analyses conducted in the systematic reviews, there was no identified effect for location, so therefore choice of location could be based on what was feasible for the investigators and participants to maximise recruitment potential and adherence.

3.1.1.1.4 Assessment selection in published studies

Numerous assessment techniques were reported for the measurement of weight status, and for specific outcomes, various methods were also used. For example, body fat percentage was measured by DEXA scans, BodPod, bioelectrical impedance scales, skinfolds and MRI scanning. Some of these methods are identified as the 'gold standard' of measurement (namely the scans) these can be expensive and time-consuming (112) and therefore, it would be realistic to include alternative, validated, methods, such as skinfolds, if conducted by appropriately qualified personnel.

The studies that involved a measure of 'the self' used various questionnaires to assess different constructs of 'the self' in youth. However, the most commonly used validated tool was the CY-PSPP (113). It assesses six dimensions of self-concept, specifically measures self-esteem in the physical domain, has been developed specifically for a youth population and has been validated with children aged between 8-12 years (114). Therefore, it would be a logical assessment option to trial.

In the assessment of FMS, all of the studies conducted product-oriented assessments (such as a throw, jump or sprint) and therefore this would suggest that these are viable measures. However, the recommendation from the systematic review was to include an assessment that involves both a product- and process-oriented component when evaluating FMS. Many of the validated methods that include a process-oriented component are based on identifying issues with movement, are time intensive, and require significant training to deliver them

effectively and furthermore, it is challenging to find an appropriate assessment method that involves both a product- and process-oriented component. Therefore, with many studies utilising product-oriented assessments successfully and the simplicity of minimal equipment, no additional training required, and less time involved, a throw, jump and sprint would be suitable and appropriate measures of product orientated FMS.

To measure strength, 24 studies reported the use of machine weights to conduct a repetition maximum (RM) assessment (between 1RM to 15RM), eight studies reported RM testing using free weights (such as squats and cleans), six studies reported using some form of dynamometer and four studies used body weight exercises (such as timed sit ups, press ups and a flexed arm hang). The majority of the strength assessments were performed on an adolescent age group and particularly for the FMS studies, included youth who were involved in a sport and were familiar with the technique of the more complex lifts (such as squats and cleans). In the primary school aged children (8-11 years), there were ten studies that reported measurement of strength. This included two studies that used dynamometry, two studies that used body weight for muscular endurance assessment, and six studies that utilised a RM protocol performed on machine weights. A limitation of dynamometry was identified as isolating certain muscle groups rather than a measure of total muscle strength (115) which is recognised by the two studies mentioned. One study measured the dominant leg only and the other measured right elbow flexors and the knee extensor muscle. RM assessments with machine weights have been identified as safe in children under 13 years provided appropriate procedures are followed (116) and furthermore, this provides a measure of maximal strength which is the key outcome of this study, as opposed to muscular endurance. Therefore, there is rationale to utilise RM measurements with machine weights to measure strength in the specified age group.

3.1.1.1.5 Published studies intervention design

There were a range of reported frequencies of sessions delivered (1-6 times a week), durations of sessions ranged from 10-90 minutes (although the 10 minute session was squats only) and duration of interventions ranged from 6-104 weeks.

Regarding programme content, there were a variety of sets and repetitions (reps) and variable intensities with some sessions being circuit based (timed exercise rather than sets and reps). With such inconsistent content it is difficult to identify a most appropriate resistance training intervention and therefore an intervention is recommended to be designed based on the UKSCA and NSCA youth RT guidelines and with consideration for what is feasible based on location and available equipment. It is important to note that in the studies that reported it, there was an average adherence reported of 85% across the systematic reviews suggesting that regardless of content, the children were compliant. Therefore, this would imply that the programme content was generally appealing to youth.

3.1.2 Feasibility study aim

The overall aim of the thesis was to evaluate the impact of a resistance training intervention study for youth. Based on previous studies and in keeping with phase 1 of the MRC framework (87), a feasibility study was first undertaken. The aim of this feasibility study was to assess feasibility of selected processes and procedures based on the outcome of the systematic reviews. These included: recruitment, participants, location, assessment, and intervention design. This was to provide recommendations to inform the design of a pilot study.

3.1.3 Methods

3.1.3.1 Recruitment

Institutional ethics committee approval was granted before the study commenced. The target group for participants was primary school age. The specific age group targeted was 8-10 years. This was due to the participants being old enough to understand instruction but still being pre-adolescent (20), therefore reducing the chance of an increase in sex hormone concentration and a resulting increase in muscle mass (24). Although, based on the systematic reviews, it could be favourable to recruit inactive and/or overweight/obese youth in the main study, initially to investigate feasibility, the decision was made to recruit all children within the specified age category, including overweight/obese. The rationale for this was to

increase the possibility of number of participants and additionally, because the purpose was to address feasibility with the specified population rather than collect data for analysis.

Two local primary schools were approached (and provided with a written proposal: Appendix 1) for involvement in the feasibility study, but one school declined to participate. Taster sessions were delivered to a primary 5 (P5) class (30 children) and a mixed primary 4/primary 5 (P4/P5) class (25 children). The 30-minute taster session included body weight exercises and some technical instruction using broomsticks (Appendix 2). Following this, a leaflet (Appendix 3) detailing the feasibility study was sent out to parents and information was provided at a parents' evening. A follow up letter (Appendix 4) regarding recruitment for the feasibility study was sent out to parents of P5 and P4/P5 children both in paper form and emailed by the school (to 55 parents).

3.1.3.2 Participants

Following the recruitment process, 55 children aged between 8-10 years took part in the taster sessions and information regarding the feasibility study was provided to all of the parents. Children were ineligible for the feasibility study if: they had a diagnosed pathological condition or disability which affects movement, such as cerebral palsy or dyspraxia, a behavioural or neuropsychological condition such as autism or attention deficit hyperactivity disorder (ADHD) or physical injury preventing testing or training. There were six initial responses and three children took part (all male). Out of the three who did not take part, the reasons identified were illness and other activities. For the children to be eligible to take part, it was a requirement that informed consent forms and health questionnaires were completed and returned prior to the start of the study (see Appendices 5 and 6).

3.1.3.3 Location

For the delivery of the intervention it was originally decided that there would be an assessment session at the University, two school-based strength sessions, two university-based strength sessions and a final feedback session involving the

children and parents. Due to a limited recruitment, the decision was made to condense the study to one assessment session, one university-based resistance training session and one feedback session. At this point a second feasibility study was proposed to trial a more thorough recruitment strategy and thus conduct a more informative study. Despite this, the reduced plan would still enable the opportunity to investigate feasibility and inform the second feasibility study.

3.1.3.4 Assessment

The three children attended a testing session where weight status, physical self-perceptions, fundamental movement skills (FMS) and strength were assessed. Following this session, accelerometers were provided to be worn for 7 days in order to measure MVPA.

3.1.3.4.1 *Weight status*

In minimal clothing and with no shoes, stretch stature and body mass were assessed to the nearest 0.1cm and 0.1kg respectively (117). Body Mass Index (BMI) was calculated and BMI Z-score for age and gender (standard deviation score) was calculated using the Cole LMS method and UK 1990 reference data (36). Weight status was classified : healthy weight as BMI Z-score <1.04 ; overweight as BMI Z-score $1.04-1.63$; obesity as BMI Z-score ≥ 1.64 (37). To assess body fat, four skinfolds were taken, (tricep, bicep, subscapular and supraspinale) (117). This method has been used previously with children (118). Girth measurements were also taken for the waist, hips, and right upper arm (117).

3.1.3.4.2 *Physical self-perceptions*

The CY-PSPP (113) was used to assess the children's physical self-perceptions. This questionnaire includes 36 statements and assesses 6 different dimensions of self-concept: sport competence, physical condition, body attractiveness, strength competence, physical self-worth, and global self-worth (33). The internal consistency of the inventory items for the subscales have been reported as follows: sports competence ($\alpha = 0.76$), physical condition ($\alpha = 0.79$), perceived body attractiveness

($\alpha = 0.82$), strength competence ($\alpha = 0.76$), physical self-worth ($\alpha = 0.88$), and global self-worth ($\alpha = 0.75$) (75). The questionnaire includes statements regarding each of these subscales and the child must identify whether they are 'really true for me' or 'sort of true for me'. The example statement on the questionnaire is 'some kids would rather play outdoors in their spare time BUT other kids would rather stay in and watch TV' and the child identifies which of those options is most like them. Following completion of all the questions, an overall score for each subscale is calculated. Due to time constraints, the questionnaire was completed at home with the parents' guidance.

3.1.3.4.3 Fundamental movement skills

A medicine ball throw, vertical jump and standing long jump were conducted to represent FMS that have been previously reported in this age group (27, 119). The children had two attempts of a counter movement vertical jump, measured in centimetres, standing broad jump, measured from back heel in metres and a seated medicine ball throw using a 2kg medicine ball, measured in centimetres (120). Best scores were recorded.

3.1.3.4.4 Strength

Absolute and relative upper and lower body strength were measured by a one-repetition maximum lift (1RM) on the leg press and chest press machines. One-repetition maximum testing has been shown to be a safe measure of absolute strength for children (116). Before attempting a 1RM, the children completed two submaximal sets of three to six repetitions with a light load. The children then performed a series of single repetitions with increasing loads. If the weight was lifted with the proper form, the weight was increased by approximately 1-5kg, and the child attempted another repetition. The increments in weight were dependent on the effort required for the lift with an aim to reach 1RM within 6 attempts. Failure was defined as a lift falling short of the full range of motion on two attempts spaced at least two minutes apart. Rate of perceived exertion (RPE) using the Borg scale (121) was also assessed to help determine load (116).

3.1.3.4.5 Physical activity levels

Each child was provided with an ActiGraph accelerometer GT3X+, a small (4.6 x 3.3 x 1.5 cm) and light (19g) triaxial accelerometer. Accelerometers were initialized and calibrated on ActiLife 6.1 software according to participant age, body mass and stature. Recording start time and end time were set to measure exactly seven days, during which time the children were asked to wear the accelerometer during waking hours. Accelerometers were set to record at a 30Hz sampling frequency, adequate for the recording of human motion (40).

For consistency and study comparison purposes, participants wore the accelerometer on their right hip. The children were instructed not to wear the accelerometer during water-submerged activities, during contact sports or during sleep. Excluding these activities, accelerometers were to be worn at all times, over or under clothing, tight enough to avoid device slipping and moving during PA. Raw data was downloaded on the ActiLife 6.1 software as activity counts at 10 second intervals. Valid wear time was defined as a minimum of four full days of recorded accelerometer data (including at least 1 weekend day), with a full day consisting of a total of 10 hours of wear time (41). A 60-s epoch was used and non-wear time was defined as strings of consecutive zeros lasting 60 min or more (42). The accelerometer output was in counts per minute (cpm). It has been reported that there are no universally agreed-upon cut-points to classify MVPA in youth with multiple cut-points available and different cut-points resulting in variable estimates of MVPA (122). In a systematic review, Youngwon *et al.*, investigated the selection of cut-points for youth and based on 11 published studies, concluded that the quality of methods used to develop cut-points was variable (122), although the most recent and rigorous validation study recommended the use of Evenson cut-points (123). Additionally, in a study evaluating the classification accuracy of five sets of ActiGraph cut-points using energy expenditure, it was reported that only the Evenson cut-points provided acceptable classification accuracy for all four levels of PA intensity (sedentary, light, moderate and vigorous) and performed well among children of all ages (124). Therefore, due to the weight in evidence, Evenson cut-points (43) were used to define time spent being sedentary (≤ 100 cpm) and time spent in MVPA

(≥ 2296 cpm). Extra activity was recorded via a physical activity diary which was free form, but with instructions (Appendix 7), to make note of estimated intensity of the activity, and additional MVPA minutes were added for children who had performed activities while not wearing the accelerometer because of water exposure (e.g. swimming). Participants were classified as 'inactive' if they did not engage in MVPA for an average of at least 60 minutes per day across the week. (12).

3.1.3.5 Strength session

The strength session was delivered in the Institute of Sport and Exercise's 'Strength Development Centre' at the University of Dundee. The session was 60 minutes duration to ensure there was enough time for a warm-up, the main exercises and a cool down. The behaviour of the children was observed to evaluate the appropriateness of the content. The warm-up was designed to increase temperature, enhance motor unit excitability, improve kinaesthetic awareness and maximise active ranges of motion (125) and it included shuttle runs with beanbags which was followed by a range of animal walks. The content was designed with enjoyment being a key factor (125) and additionally to enable participants to develop control of their body mass (126). The range of sets and reps followed recommendation by the UKSCA for a youth beginner (11) and exercises were performed with a light weight initially to ensure technical competency, as this is a key factor identified by both the UKSCA and NSCA (11, 20). Additionally, the use of body weight and free weights were included as they provide a full body movement to challenge major muscle groups and control of body mass in a variety of push, pull, squat and lunge movements to develop foundational strength (127). The use of a medicine ball was beneficial due to being easy to hold and handle (128). Based on these guidelines, the session content is shown in Table 1.

Table 1 Strength session content (a)

Exercise	Sets/Reps
Squat with a medicine ball held at the chest	2x8
Push ups (on knees if required)	2x8
Walking lunge (medicine ball overhead)	2x8
Front plank wrestle game	2x30s
Single leg squats off plyometric box	2x4 each leg
Pull ups (bands if required)	Maximum reps

3.1.3.6 Feedback session and questionnaire

Following the strength session, the feedback session took place at the University with both the parents and children in attendance. An online questionnaire using Bristol Online Surveys was also established and emailed out by the school to the parents of all of the P4/5 and P5 children who were involved in the taster sessions (55 children).

The online questionnaire included two open answer questions:

- My child did not attend the project due to:
- What can we do to assist you in having your child involved in the project?

During the feedback session, (children, n = 3, parents, n = 3) the topics that were explored were location, likes and dislikes, and logistics, and during the discussion notes were taken (the questions and responses from both the feedback session and questionnaire can be found in Appendix 8 and further details are in the next section).

3.1.4 Results

3.1.4.1 Feedback session and questionnaire

Detail regarding the feedback session can be found in Appendix 8. In summary, the University was the preferred location, the content was enjoyable and there were some challenges with elements of the assessment. Regarding the frequency of sessions, there was some suggestion that twice a week might be excessive and it would be advantageous to have more days available for the sessions. From the online questionnaire, there were 16 responses from 55 (29% response rate) and the responses can be found in Appendix 8. In summary, the majority of responses were individual with no themes emerging and therefore were difficult to take into consideration. Specific aspects of feasibility were evaluated and are detailed in the sections below.

3.1.4.2 Issues with recruitment

Response rate was low to the initial call for participants with only 5% of the children who took part in the taster sessions taking part in the study. Comments from the feedback session and questionnaire indicated that lack of notice and proximity to Christmas were the most common reasons for lack of engagement with the study.

3.1.4.3 Participants

All participants were male (mean $\pm$ SD, age = 8.7 $\pm$ 0.6 years, body mass = 32.9 $\pm$ 8.2kg, stretch stature = 135.4 $\pm$ 4.7cm, BMI Z scores = 0.69 $\pm$ 1.58) with one participant classified as obese and two classified as healthy weight. All three met the physical activity guidelines based on the accelerometer data (mean $\pm$ SD, 170 $\pm$ 41 mins average MVPA per day).

3.1.4.4 Location

From comments from the feedback session/questionnaire and due to the environment and available equipment, the University was the preferred location as

an after-school activity, twice a week maximum. From the questionnaire some parents had suggested that a school pick up would be beneficial.

3.1.4.5 Assessment

The assessment of weight status took approximately five minutes per child and there were no identified issues. At the time, the children said they were comfortable with the assessments and this was also supported during the feedback session. As the CY-PSPP was completed at home, the feedback from the parents was that some children did not understand the questions and that it took a long time to complete. Furthermore, one parent suggested 'body attractiveness' questions were not appropriate. For the FMS measures, it was noted at the time from observation that the quality of movement was questionable due to focus on outcome rather than the quality of movement. Additionally, during the feedback session it was identified that the instructions were not clear which could have had an impact on the outcome.

When measuring strength, due to adult sized machines, it was necessary to put rubber bumpers under feet to perform the chest press and the positioning of a seated machine was difficult. It was important to note that from observation, facial expressions did not equate to RPE, so RPE was crucial in determining effort. For the leg press, again due to the size of child, it was not possible for there to be the desired 90 degree angle at the knee as a start point in some of the children. Despite these limitations, the children did identify that they enjoyed the challenge of a maximal effort and there were no adverse physical effects reported. Finally, regarding the accelerometers, the children identified that there was too much strapping and it was annoying to wear, however they all managed the required wear time.

3.1.4.6 Strength session

From observing the behaviour of the children during the session, although the children appeared to enjoy the animal walks, despite emphasis on the movement being slow, silent and under control, a competitive element became apparent rather than quality of movement. Concentration levels were low throughout, however,

technically, the children could perform most of the exercises. From the feedback session information, the children identified that they specifically enjoyed pull ups and the plank challenge. Finally, the children also suggested that twice a week would be a suitable frequency of sessions, although some comments from parents suggested twice a week might be excessive.

3.1.5 Discussion

The aim of this feasibility study was to assess feasibility of selected processes and procedures based on the outcome of the systematic reviews. These included: recruitment, participants, location, assessment and intervention design. The overall aim of this process was to provide recommendations to inform the design of a pilot study.

In summary, the recruitment process was not successful and therefore further planning would be required in strategy development to ensure a greater recruitment potential. Regarding participants, the target age group was as planned, one participant was classified as overweight/obese and all three participants met the guidelines for MVPA. The location was deemed as suitable for delivery of the assessments and intervention and delivering the intervention content provided valuable information to enable adjustments to be recommended. The children stated that they enjoyed the sessions, which is a key component of future intervention development. Finally, frequency and duration of sessions were considered, but clarity on the best approach was not possible due to a limited number of sessions delivered and further investigation into an appropriate duration still being required. Overall, this study allowed an initial period of preparation to inform a controlled trial design but due to specific challenges, a further feasibility study based on the following recommendations was advisable before designing a pilot study.

3.1.5.1 Recruitment evaluation

The decision was made to recruit children of all weight statuses, as well as not specifying level of physical activity as selection criteria so to optimise recruitment

opportunity. However, other factors influenced the limited recruitment and on reflection, more time should have been spent planning the recruitment process. Therefore, a more detailed recruitment strategy would be recommended for the second feasibility study with sufficient notice for parents and based on the principles outlined by Foster *et al.* (129) and a business model approach developed by Francis *et al.* (130) and this is explored in more detail in Chapter 3, part b. Furthermore, uncertainties remained regarding optimal recruitment of participants to ensure sufficient numbers to enable a control group.

3.1.5.2 Participant details

Concerning the participants, with one participant being overweight/obese and all three being physically active, this did not meet the proposed selection criteria for the pilot study, although this was not identified as selection criteria for the present feasibility study and it would be recommended to employ the same approach for the second feasibility study. Regarding age, there is previous rationale to support the target age group of 8-10 years and the assessments and intervention content appeared to be appropriate for this group. To maximise the recruitment potential, the recommendation for a second feasibility study would be to target all healthy children between the ages of 8-10 years.

3.1.5.3 Location evaluation

Considering location, there were several studies that implemented community-based interventions identified in the systematic reviews. Based on this feasibility study, a community-based intervention at the University would be advised for a second feasibility study for various reasons including the environment, equipment, and 'after school' activity rather than being school related.

3.1.5.4 Review of assessments

In evaluating the assessments, the weight status measures were conducted successfully and therefore it would be recommended that they remain the same for a

second study. The CY-PSPP assessment tool appeared to be appropriate, however should be adapted due to some difficulties in completing it. It would be advised to conduct the questionnaire face to face with the children, with the questions being read by the researcher and allowing questions to be asked in cases of uncertainty. Although one parent identified 'body attractiveness' as an awkward topic, with just one parent identifying this, the recommendation would be to keep it in for a second trial of the protocol. The FMS assessment was challenging due to the lack of quality of movement when conducting a product-oriented assessment and therefore it is deemed important to include a process-oriented element as recommended by Logan *et al.* (58). The FMS assessment focussed on product outcomes so therefore it would be beneficial to implement a 'battery' that assesses both product and process outcomes, which may be more advantageous compared to individual FMS assessments (58). The Canadian Agility and Movement Skill Assessment (CAMSA) (131) is an appropriate assessment tool that would be recommended to be trialled in a second feasibility study.

Regarding strength testing, the adult sized machines were not advisable for this age group. Although safety and efficacy of maximal strength testing has been previously evaluated (116) the testing was conducted on equipment specifically designed for children. Other methods have included dynamometry although a limitation of this was identified as isolating certain muscle groups rather than a measure of total muscle strength (115). With limitations of equipment, selecting a method that ensures a measure of total muscle strength which does not compromise safety or requires significant familiarisation and technique development is essential. Based on this, the Smith machine (squat and bench press) would be a recommended option to be trialled in the second feasibility study due to being less restricted than a fixed machine. Further rationale for choosing this assessment is that the squat, in particular, is more specific to the exercises the children would do in the intervention study but for assessment of maximal effort, the Smith machine provides safety rather than using a barbell, which would require technical competency. Furthermore, it is important to note that the children identified the maximal lifting as enjoyable, which is consistent with the findings from Faigenbaum *et al.* (116). Finally, the only issues identified regarding accelerometer wear was that the straps were long and therefore could be put in place using Velcro in the second feasibility study.

3.1.5.5 Strength session evaluation

In evaluating the strength session, although the content was based on the evidence outlined in the method session, on reflection, with the lack of concentration and difficulty in monitoring load, the recommendation for a second feasibility study would be to include more barbell and dumbbell exercises. This is supported by the NSCA provided that light loads are initially used and the focus is on enhancing movement patterns (20). Additionally, it would be advised that the sessions be reduced from 60 to 45 minutes in duration to encourage more focus, particularly as it is vital that technical competency is prioritised (11). As the children specified that they enjoyed the challenge of the maximal strength testing, this would suggest that lifting a load would be a gratifying activity and this is a key component as enjoyment has been shown to mediate the effects of youth PA programmes (132). It was identified that there should be more days available for participants to choose from however, this would depend on how many children were recruited in a second study. There was some suggestion that two days a week might be challenging for attendance, however, for a second feasibility study two sessions a week would be recommended, particularly because previous research has demonstrated greater effect with twice weekly, over once weekly, sessions (133).

In summary, the feasibility study was beneficial in providing information to design a future study, however, there were still uncertainties in some areas and therefore it was valuable to do further feasibility work on a larger scale, based on the recommendations, before designing a pilot study.

3.2 Part b

Based on the evaluation of the initial feasibility study, it was decided that a second feasibility study would be conducted. Following recruitment there were baseline assessments, a resistance training intervention, a post intervention assessment and, finally, a feedback session with the children and parents in attendance to evaluate the process. Based on the recommendations from part a, the aim of the second feasibility was to provide additional rigour to the design of the pilot study through addressing any previous uncertainties regarding feasibility.

3.2.1 Methods

3.2.1.1 Recruitment

Institutional ethics committee approval was granted before the study commenced. Foster *et al.* identified a series of recruitment principles to provide guidelines to maximise recruitment potential (129). Based on this information, the relevant principles were applied to develop a recruitment strategy. In particular: allowing more time for recruitment, recruiting where the children are located and getting feedback on the recruitment approach. Using a business model approach, Francis *et al.* developed a reference model using insights from social marketing theory. The model has four domains: (1) Building Brand Values (2) Product and Market Planning (3) Making the Sale and (4) Maintaining Engagement (130). This can be applied to developing an intervention study by making sure it is clear what the trial 'stands for' and what the brand values are (130). For this feasibility study, the project was called 'Active Strength', with the tag line of "fun, healthy, active, safe". Leaflets (Appendix 9) were produced to provide the parents with details of the study. A WhatsApp group was established to provide an easy contact option for the parents and an opportunity for engagement by including photos and videos of the children taking part in the sessions (with permission). A private Facebook group was also created to provide an additional educational element with relevant articles posted for the parents as well as photos and videos of the children.

Taster sessions were delivered that involved body weight and broomstick exercises due to limited equipment at the schools and a consistent content across all schools (Appendix 2). Following the taster sessions, letters including information to be emailed to parents (Appendix 10) and leaflets (Appendix 9) were sent to 15 schools to be forwarded on to parents regarding the feasibility study. Additionally, a video including the study details was produced and posted on social media channels to ensure the overall research question, importance of the study and details were clear (Appendix 11). Finally, an open evening was organised at the University to present study details to parents and to provide an opportunity for the children to take part in a practical session whilst they could observe the type of content that would be delivered during the study (Appendix 12). The numbers recruited from each strategy are detailed in the results section.

3.2.1.2 Participants

As detailed in 3.1, part a, children were ineligible if: they had a pathological condition or disability which affects movement, such as cerebral palsy or dyspraxia, a behavioural or neuropsychological condition such as autism or ADHD or physical injury preventing testing or training. There were 14 children recruited between the ages of 8-10 years and with three days available to choose from for the strength sessions. Based on the children's availability, the group naturally split into two. The group was then assigned to either an experimental group (EG) or control group (CG). In the EG there was one female and five males and in the CG there were two females and six males. The EG took part for the first four weeks and then the CG took part for the following four weeks. The CG was offered the follow-up RT intervention to ensure they received a benefit of being part of the study, but this also allowed an additional four weeks of evaluation of the intervention content. All participants in the CG took part in the intervention.

3.2.1.3 Assessment

The baseline assessment included attendance at two 1-hour sessions. In session one, one repetition maximum (1RM) squat and bench press on the Smith machine, following the same protocol as described in part a, and anthropometric measures

(described in 3.1, part a) were taken. In the second session, the CAMSA (131) and the CY-PSPP (113) were completed.

The CAMSA is a standardised assessment that has been shown to be a feasible, objective and reliable measure of FMS in children aged 8-12 years (131). The assessment requires jumps on two feet, one footed hopping, throwing and catching on the run, dodging from side to side, and the kick of a football (131). To conduct this assessment, following the guidance outlined by Longmuir *et al.* the children should be instructed to complete the assessment as fast as possible while performing the skills to the best of their ability following two demonstrations (131). The first demonstration should be done slowly, with each skill explained as it is demonstrated, and the second demonstration should indicate the effort and speed required. Each child should perform two timed and scored trials. Timing starts on the “go” command and ends when the child kicks the football. Verbal cues should be given throughout the assessment to minimise the impact of memory on task sequence and completion time. No feedback should be provided on task performance and no attempt should be made to encourage or alter the child's performance. The time required to complete the course should be recorded, and then converted to a point score (range 1–14 points). The quality of each skill (2-footed jump, side slide, catch, throw, skipping, 1-footed hop, and kick) should be scored as either performed (score of 1) or not observed (score of 0) across 14 reference criteria (0–14 points). The total score (maximum 28 points) is calculated as the sum of the skill and time scores (131).

The CY-PSPP (113) was conducted to assess the children's physical self-perceptions. This is described in part a, but during this study it was completed during the session with the researcher reading out each question and the child writing down their response with guidance from their parents.

For monitoring of physical activity levels, accelerometers had additional Velcro to secure the straps and were handed out with instructions to parents (Appendix 7) who were asked to ensure their child wore it for 7 days. As previously stated, participants were classified as ‘inactive’ if they did not meet the physical activity guidelines for MVPA (12).

3.2.1.4 Intervention content

The intervention consisted of twice weekly 45-minute strength sessions for four weeks. It was important to investigate the feasibility of attending twice a week as research has found more benefit from two sessions rather than one (133). As the aim of this study was not to investigate the effects of the intervention, it was deemed that four weeks was sufficient time to investigate the appropriateness of the content. There was a second assessment after the first four weeks to see if the control group would still complete the assessment despite four weeks of no intervention and also to increase the number of participants to evaluate the feasibility of the assessments. To clarify for the children why they were part of the study, they were shown a video of children weightlifting and given a recap on why being strong was important for them. The initial content was similar to what was delivered during the initial feasibility study; the final programme content can be seen below.

Table 2 Strength session content (b)

Exercise	Sets/Reps
Warm up games - pass the broomstick, bean game.	5 Minutes
<i>Key exercise 1</i> - bean bag lunges + overhead lunges	2 x 8 (1 set of each type of lunge)
<i>Key exercise 2</i> - deadlift	2 x 8
<i>Key exercise 3</i> - wheelbarrow obstacle course	10m course
<i>Key exercise 4</i> - overhead squat (broomstick) + back squat with 5kg bar	3 x 8 (1 set with the broomstick and 2 sets with the bar)
Hanging challenge – hang from a pull up bar and then progress to kicking a ball thrown to them.	Maximum hang time

3.2.1.5 Feedback Session

Following the intervention period, a feedback session was conducted with the children and parents of the intervention group in attendance together, although not all could attend (children, $n = 4$, parents, $n = 4$). Additionally, the parents of the children who were not available and of those in the control group were asked for feedback via WhatsApp and email. The aim of this was to explore what the children liked and disliked about the intervention and to gain feedback on the assessments and the Strength Development Centre. The parents were asked about logistics of attending and for comments on improving recruitment. The questions and responses can be found in Appendix 13.

3.2.2 Results

3.2.2.1 Feedback session details

Detail regarding the feedback session can be found in Appendix 13. In summary, there was mostly positive feedback regarding the intervention content and assessments with some adaptations suggested. There were some logistical issues identified by parents and some suggestions to maximise recruitment. The specifics are detailed in each section below.

3.2.2.2 Recruitment strategy effectiveness

Regarding the taster sessions, there was a positive response from nine out of the 15 schools contacted (60%). In total there were sixteen, 30-minute taster sessions delivered to 440 children. From these sessions, there was a 0.7% sign up to the study. Concerning the follow up open evening, there were 14 parents present and 12 children. Out of the 12, eight signed up (67%). Additional to the eight who signed up at the open evening, there were six more children who signed up. Out of the 14, five of the parents found out about the project via social media, two found out via word of mouth, seven were through the schools (three had taken part in a taster session).

The WhatsApp and Facebook groups were positively received by the parents as mentioned in the feedback session. Regarding suggestions for recruitment, advertising in schools and the opportunity to see the programme content in the parent information session was viewed favourably. Other locations were recommended and free membership to the University facilities for parents was mentioned.

3.2.2.3 Participant details

Data are presented as mean $\pm$ SD. There were 14 children (age 8.87 $\pm$ 0.92 years) who were assigned to either the EG (n = 6, age 8.83 $\pm$ 0.90 years, body mass = 34.4 $\pm$ 9.0kg, stretch stature = 136.0 $\pm$ 5.9cm, BMI Z score = 0.88 $\pm$ 0.49) or CG (n= 8, age 8.88 $\pm$ 0.93 years, body mass = 34.7 $\pm$ 6.9kg, stretch stature = 136.6 $\pm$ 5.1cm, BMI Z score = 1.43 $\pm$ 1.05). Two participants in each group were classified as overweight/obese (33% and 25% respectively and 29% across all participants). The average daily MVPA for the EG was 63 $\pm$ 24 mins and for the CG was 92 $\pm$ 33 mins, however, the percentage of children who did not meet the guidelines for MVPA was 43% (six out of 14). 50% of participants were classified as inactive or overweight/obese (67% in the EG and 38% in the CG),

3.2.2.4 Assessment evaluation

The weight status measures were successfully conducted as they were in the initial feasibility study. When conducting the CY-PSPP (113), there was some embarrassment and upset from the children regarding the 'body satisfaction' questions. The CAMSA assessment (131) was conducted successfully however the 1RM assessment on the Smith machine was difficult for the children due to technique and did not provide a robust measure of strength. Additionally, in the feedback session, one parent commented about not being comfortable with the amount of weight on the shoulders of their child. The sessions did not take as long to complete as first anticipated. Finally, based on the feedback session information, some of the children found wearing the accelerometers difficult due to the straps and other children at school were making fun of the children for wearing it.

3.2.2.5 Intervention content

The intervention content was similar to the first feasibility study, however, from observation, initially concentration levels were low in some of the children and 'readiness to lift' as identified by the NSCA and UKSCA was an issue. However, after this was brought to the attention of the parents, it was decided that they would continue with the sessions. When a 'deadlift' was introduced along with more emphasis on weight room etiquette and 'earning the right' to lift more weight once they were technically competent, the children became more focussed. From observation, the children also appeared to find the lifting more fun.

To monitor progress, the children were given record sheets, but this proved too time consuming and some stated that they found it difficult to understand. The children also found push-ups too difficult and did not appear to enjoy them due to lack of success, so a wheelbarrow obstacle course was introduced which was a positive addition. Furthermore, pull ups were also too challenging so the 'hanging challenge' was created, which they all could participate in and enjoyed (supported by the feedback group information). With the control group, the lifting and emphasis on weight room etiquette began at the beginning, with no animal walks included and more clarity regarding the aims of the study.

It became apparent through observing behaviour that the message about why they were involved was not clear. Thus, more equipment was added to ensure the facility was established as a weights room and due to the programme becoming less movement based (i.e. less content such as animal walks), the issue of the size of room (identified in the feedback session) was no longer a problem. Regarding duration of the sessions, the feedback from the parents in the feedback session was variable with some suggestion that the session duration was long enough for the parents to do an activity during the time, yet another suggested it was not long enough for this purpose. Similarly, there was a comment that straight after school was a good time to take part in the sessions, yet another comment was that it was a

rush to get to the facility. Finally, regarding frequency of sessions half of the parents stated two sessions a week was too many.

There was 100% attendance from both groups at the sessions and following the intervention, in general, the feedback was very positive:

“X is buzzing like this from anything else he’s done, this could do wonders for his confidence.”

“I know he’s really going to miss coming on a Tuesday and Thursday! He’s wanting me to buy him a set of dumbbells!”

“X has finally found something he enjoys.”

3.2.3 Discussion

Based on the recommendations from part a, the aim of the second feasibility was to provide additional rigour to the design of the pilot study through addressing any previous uncertainties regarding feasibility. The main areas addressed were: recruitment, participants, location, assessment and intervention content.

In summary, the recruitment process was successful and therefore a similar process would be recommended for the pilot study. Regarding participants, the target age group was as planned, 29% of participants were classified as overweight/obese, 43% were classified as inactive and 50% were either overweight/obese and/or inactive. Thus, without specifically aiming to recruit overweight/obese and/or inactive participants, the content of the study was appealing to a significant number within this category, which was promising for future recruitment. The location was deemed as suitable for delivery of the intervention. The delivery of the assessment and intervention content provided valuable information with few adjustments recommended for the main study. Adherence was excellent with enjoyment being reported by the children; and duration, frequency and timings of the intervention were all evaluated and no changes recommended. Overall, this second study allowed a thorough evaluation of feasibility to enable a robust pilot study to be developed.

3.2.3.1 Recruitment strategy evaluation

Regarding recruitment, 14 was deemed a sufficient number to make sound conclusions to inform the pilot study. Similar studies, although specifically targeting overweight/obese children, have recruited between 19 and 78 children (134-137), which is promising in supporting a target recruitment of this population in the pilot study. These studies were longer duration so possibly more appealing as an after-school activity and it would be recommended that the duration of intervention would be longer in the pilot study. It has been suggested that to develop strength, interventions should be at least eight weeks in duration (20).

Based on the recruitment principles identified by Foster *et al.* (129) and the reference model developed by Francis *et al.* (130), having sufficient planning time, recruiting through the schools, building the brand values, making the sale and maintaining engagement were fundamental as part of the recruitment strategy. In this instance the 'Active Strength' brand was clear and the tag line of "fun, healthy, active, safe" helped provide the parents with the key messages regarding the project details. As well as targeting the parents to 'make the sale' (130), time was spent making sure that the children understood the importance of the project for them. This was supported by a quote from one of the parents: *"X is so excited and proud – she is telling everyone about it. She feels important!"* The parents evening was successful with recruiting a large proportion of the cohort and this again was supported with comments from the feedback session that it was beneficial for the parents to see what the content would be like. The WhatsApp group was particularly beneficial in maintaining engagement with the parents and the Facebook group provided a platform to provide educational material and share content from the strength sessions.

In a previous study that recruited pre-adolescents for a community based resistance training programme, Mullane *et al.* (138) also provided leaflets for parents, delivered a parents information evening and recruited 20 children for the study. There have been additional community based studies who have successfully used links with

schools to issue information to parents (29, 137) and recruit children for their studies (78 and 22 respectively). Taster sessions were not included as part of recruitment strategies in the studies included in the systematic reviews, which might explain why it was not an effective method in the current feasibility study. However, despite this, the taster sessions did provide the opportunity to make links with local schools, which appears to be an effective and commonly used recruitment strategy and furthermore, was supported in the feedback session discussion. Social media was not identified as a recruitment tool in any of the studies included in the previous research, however, there were five participants recruited via this method in the current feasibility study and therefore it would be recommended as a recruitment tool for the pilot study. There were comments in the feedback session information about a different location and free membership for parents but as recruitment was successful in this study, this was not taken into consideration at this time. Overall, for the pilot study it would be recommended to have letters and leaflets sent out from schools to parents, advertise via social media, host an open evening to ensure the parents are clear about the project details, provide sufficient notice and to ensure the children are clear about the importance of the project for them. Furthermore, a WhatsApp group and Facebook page would be recommended as beneficial to maintain engagement.

3.2.3.2 Participant details

Although advertised as mixed sex training group there were only three females involved, which might be due to stereotypic perceptions (139). With half of the cohort being either inactive or overweight/obese, this is encouraging for a targeted recruitment of this population for the pilot study. The studies included in the systematic reviews with similar recruitment techniques were focussed on a similar target group with successful outcomes (overweight/obese children in particular) (29, 137, 138). Furthermore, as previously mentioned in part a, there is evidence to support the target age group so again, it would be recommended to remain the same for the pilot study.

3.2.3.3 Location evaluation

The University environment was agreeable, with some adaptations made during the study regarding the set up in the 'Strength Development Centre' to create a positive and focussed environment. As previously mentioned, several studies have successfully delivered community-based interventions and therefore it would still be recommended that the intervention would be delivered at the University in the pilot study.

3.2.3.4 Review of assessments

The assessments process was positive with no further recommendations for the measurement of weight status and additional improvements were evident in the delivery of the CY-PSPP and the introduction of the CAMSA assessment. The CAMSA assessment was particularly appropriate as it includes both a product and process element in the assessment of FMS which is deemed to be important when evaluating FMS in children (140). The only suggestion for conducting the CY-PSPP again would be that the questions on 'body attractiveness' should be removed in the pilot study. These questions caused some upset and are not relevant to the main outcomes of this thesis. It is however important to note that the questionnaire has successfully been used with this age group previously (141). There were still identified difficulties with conducting the strength measures which would need to be addressed for the pilot study. An isometric mid-thigh pull is a recommended measure of strength as it assesses peak force and has been used successfully in youth populations (142). While this was not used in the studies included in the systematic reviews, it is a validated method, and with equipment availability, this would be recommended as a viable option. Regarding order of assessments, this was consistent for all participants; specifically, it would be recommended that the CY-PSPP should be done before the strength assessment to ensure limited response bias. Finally for accelerometer wear, sufficient data was obtained, however, due to the long straps and children being mocked at school it would be recommended to shorten the straps and provide information to the school detailing that the children

will be wearing them and for the teachers to acknowledge this so the other children are aware.

3.2.3.5 Intervention evaluation

The strength sessions were effective with a change of focus to be on more dumbbell and barbell exercises and the children identified that they enjoyed the sessions which was supported by positive quotes. This is also supported by the 100% attendance. Several studies have implemented a RT intervention successfully, with attendance figures including: 74% (49), 87.5% (143), 89% (144) and 98% (134). A recommendation for the pilot study would be that the children record loads lifted for motivation. Although monitoring load appeared to be challenging for the children, it is an important task to monitor progress and provide the children with responsibility and ownership. This is consistent with the Self Determination Theory regarding an autonomy-supportive environment (145) which has been shown to correspond to greater intrinsic motivation (146). Thus, more support to enable the children to complete this task would be advisable. Finally in addressing frequency and duration of the sessions, twice a week was feasible for half of the parents and the 45 minute sessions after school was successful (despite one parent identifying that it was not long enough), so it would be recommended to keep this format in the pilot study.

3.2.4 Conclusion

In summary, these two feasibility studies were invaluable in developing and designing an intervention for the pilot study. The recruitment strategy was modified and was successful in recruiting sufficient numbers for a meaningful second feasibility study, with robust recommendations for the pilot study. The assessments and RT intervention were trialled and modified with further recommendations made, supported by the feedback session.

CHAPTER 4: Pilot Study

This chapter has been taken from a submitted manuscript that at the time of the submission of this thesis, was under review for publication. Sections of this chapter have now been published (147).

The impact of resistance training on strength and correlates of physical activity in youth.

ABSTRACT

Resistance training (RT) may have a positive impact on specific correlates of physical activity (PA) with strength identified as a possible underlying mechanism. This pilot study investigated the impact of RT on strength and correlates of PA in inactive and/or obese youth. Twelve participants (aged 8.9 ± 1.0 years) were assigned to an experimental group (EG) or control group (CG). Pre and post intervention assessments for strength, physical self-perceptions (PSPs), weight status, fundamental movement skills (FMS), and PA levels were completed. The EG participated in a twice-weekly 10-week RT programme. There were significant group x time interactions for FMS (CAMSA total $P=0.016$, CAMSA skill score $P=0.036$) and stretch stature ($P=0.002$) with the EG displaying larger changes than the CG. Large effect sizes for the differences in change scores between the EG and CG were evident for CAMSA total score (Hedges' $g=0.830$, $P=0.138$), CAMSA skill score (Hedges' $g=0.895$, $P=0.112$) and relative strength (Hedges' $g=0.825$, $P=0.140$). There was not sufficient data regarding PA levels to conduct statistical analysis, although a trend towards a decrease was apparent with a larger decrease evident in the CG. This study demonstrated that a 10-week RT intervention has a positive effect on FMS and may also benefit strength, weight status and PSPs. This study supports the development of RT interventions for inactive and/or obese children to develop these correlates, and ultimately increase PA levels.

KEY WORDS: Strength, health, children, active, movement, obesity

INTRODUCTION

The positive effects of physical activity (PA) on the health and well-being of youth are well established with recent reviews stating that appropriate levels of PA reduces the risk of several diseases (e.g. diabetes, cardiovascular disease) and contributes to the development of healthy musculoskeletal tissues, the cardiovascular system and neuromuscular awareness (12). Regular participation has the potential to improve a child's emotional, social and cognitive well-being, as well as health and physical fitness (148).

One of the key identified consequences of not being sufficiently active is the increased chance of obesity; childhood obesity is associated with a higher chance of obesity, premature death and disability in adulthood (8). In addition to increased future risks, obese children experience breathing difficulties, increased risk of fractures, hypertension, early markers of cardiovascular disease, insulin resistance and negative psychological effects (8). The World Health Organisation (WHO) reported that 340 million youth worldwide aged 5-19 were overweight or obese in 2016 (8) and in Scotland in 2019, 16% of children were identified as being at risk of obesity (9). Owing to the high risk of overweight youth becoming obese adults, Hills *et al.* reported that the engagement of youth in physical activity is a fundamental component in the prevention of obesity (10).

The current United Kingdom (UK) PA guidelines for youth aged 5-18 recommend moderate-to-vigorous intensity physical activity (MVPA) for an average of at least 60 minutes per day across the week (12) and there should be a variety of types and intensities of PA to develop movement skills, muscular fitness, and bone strength (12). There should also be minimal sedentary time (12). However, despite these guidelines, one of the more recent global surveillance studies, the Health Behaviour in School-aged Children survey (HBSC), reported that across Europe and North America, less than 50% of young people were meeting the recommended MVPA recommendation (15). PA levels also demonstrate a decline with age; 25% of 11 year olds meeting the recommendations compared to just 16% of 15 year olds (15). This indicates that as children advance through adolescence, physical inactivity becomes ubiquitous.

Identifying the importance of strength and movement skills as part of the PA guidelines, Faigenbaum *et al.* stated that low levels of muscular strength and power (dynapenia) negatively impact physical, psychosocial, emotional, and behavioural factors that drive physical inactivity in youth (19), therefore this implies that strength-based exercise or 'resistance training' is an integral part of PA for youth.

The National Strength and Conditioning Association (NSCA) and the United Kingdom Strength and Conditioning Association (UKSCA) have developed position statements emphasising why youth should engage in RT (11, 20). Research indicates that appropriately designed, and well supervised RT programmes can benefit youth of all ages, with children as young as 5 years of age making noticeable improvements in strength (27). Specifically, RT provides an additional stimulus to the neural maturation taking place, resulting in further development compared to youth who do not take part in RT (149). Additionally, RT has numerous health benefits for youth and an appropriate programme has been shown to improve bone health (28), decrease cardiovascular disease risk (20), decrease metabolic risk factors, improve body composition (29) and improve self-esteem (30). Motor skills (such as jumping, running, throwing) have also been shown to be improved in youths after a period of resistance training (20). The importance of RT as a mode of PA is clear due the associated health benefits and its inclusion in the PA guidelines. An additional advantage of RT could be a positive impact on MVPA, which is indirectly supported by the 'Pediatric Inactivity Triad' (PIT) which proposes that low muscle strength (dynapenia) is associated with low levels of MVPA (16).

When considering if there is a direct impact of RT on PA levels, there are only two studies to date that have investigated the effect of RT on PA levels. They found significant increases in daily spontaneous PA in 10-14 year olds following a RT intervention (32, 33). Meinhardt *et al.* included 102 children (42 girls 60 boys) who took part in a school-based resistance training programme (32). There was a significant increase in daily spontaneous PA in the boys but not the girls. However, the age range spanned across different pubertal stages with most of the girls being pubertal in contrast to the boys who were mainly prepubertal. The difference in findings between sexes may therefore be due to an increase in sex hormone

concentration and a resulting increase in muscle mass (24). It was also unclear whether the children were sufficiently active prior to the study, and it was not apparent if there were significant differences between the boys and girls at baseline (32). In Eiholzer *et al.* 46 boys participated in the study from two local ice hockey teams which involved taking part in supervised resistance training (33). They found a significant increase in PA compared to the control group, despite both experimental and control groups being competitive ice hockey players (although it was not clear how often they trained per week). Whilst promising, these studies only demonstrated significant findings in males and did not explore the potential underlying mechanisms of the effect, although in both studies there were significant increases in strength. However, in the Meinhardt *et al.* study, increases in strength were identified in both the boys and girls, despite the girls not showing a significant increase in PA (32, 33). Overall, these studies concluded that RT could be used as a strategy to increase PA levels, but further investigation is required to substantiate this effect, particularly in inactive individuals.

There is some evidence to support the association between RT and PA levels but there is no evidence that supports possible mediators of this association. RT has been shown to have a positive impact on weight status, fundamental movement skills (FMS) and 'the self' and these outcomes are identified as being associated with PA (thus, correlates of PA) and therefore may be important mediators of a possible effect of RT on MVPA. Additionally, as RT has been found to increase strength in youth, it may be proposed that strength could be an underlying mechanism that could explain a positive effect of RT on the correlates of PA.

To investigate the association between weight status and PA, Strong *et al.* reviewed cross-sectional and longitudinal observational studies that concluded that youth of both sexes who participate in relatively high levels of physical activity have less adiposity than inactive youth (43). More recent studies have reported associations between weight status and PA (44-46). Considering specifically RT as a strategy to treat and/or prevent obesity, there are systematic reviews that have explored the impact of RT on weight status (47-51) and the rationale being that there could be an increase in skeletal muscle mass and resulting increase in basal metabolic rate (38). Investigating the impact of RT on weight status in youth, a recent meta-analysis

reported statistically significant effect sizes for skinfolds (Hedges' $g = 0.274$, $P = 0.01$) and body fat percentage (Hedges' $g = 0.215$, $P = 0.007$) (83). However, the review highlighted that the evidence base is not strong with substantial variability among intervention design across 18 studies, and with just 44% of included studies classified as 'strong'. Furthermore, the majority of research investigates multi-component interventions, so it is difficult to isolate the effect of RT (47, 49).

A recognised complication for overweight children with regards to PA is that they have difficulty performing fundamental movement skills (FMS) (150). Strong evidence has been reported for a positive association between FMS competency and PA in youth (52, 60, 151). FMS are commonly categorised as locomotor (e.g. running, jumping), stability (e.g. balancing, twisting) and object control (throwing, catching, kicking) (52) and could be described as 'building blocks' of more complex movements (140). It has been suggested that if muscular strength and FMS are not enhanced early in life this may hamper a child's ability to participate in a variety of activities and sports in later life (31). The PIT model also alludes to an association between muscular strength and FMS (16). In support of this, there were statistically significant effects reported of RT on specific FMS in youth (vertical jump, squat jump, standing long jump, spring and throw) following a meta-analysis of 22 studies (84). Both functional (e.g. changes in motor unit coordination) and structural (e.g., muscular hypertrophy) adaptations as a result of RT might bring about changes in motor competency (152), which may be linked to the development of FMS.

In addition to FMS, the PIT model also identifies that 'physical illiteracy' also includes lack of confidence, and knowledge to move proficiently in a variety of physical activities (16). There is a consensus for an association between PA and constructs relating to 'the self' (e.g. self-esteem, self-concept, physical self-perceptions) in youth (66, 67, 75). Despite some limitations regarding methodological design, collectively these reviews provide convincing evidence of an association between PA and 'the self'. Furthermore, a previous systematic review investigated the impact of RT on 'the self' in youth with reported statistically significant effect sizes for resistance training efficacy, perceived physical strength, physical self-worth, and global self-worth (85). Indirect support also comes from studies that demonstrate a

positive association between muscular fitness and physical self-perceptions (38). For example, in a systematic review, Lubans *et al.* (77) reported evidence of an association between muscular fitness and physical self-perceptions (perceived physical performance and perceived sports competence), overall physical self-worth and global self-esteem in youth.

Hence, although there is evidence to support the effect of RT on these correlates of PA, the research is not substantial and warrants further investigation. Furthermore, it remains uncertain as to whether there is an effect of RT on PA levels, and whether this effect is mediated by weight status, FMS and 'the self'. Therefore, the aim of this study was to investigate the impact of a RT intervention on strength, correlates of PA (weight status, FMS and 'the self') and MVPA, in inactive or overweight/obese youth.

METHODS

Ethics and Recruitment

Institutional ethics committee approval was granted before the study commenced. Information leaflets were displayed on social media and sent out to nine local primary schools. Eligible participants were primary school students aged 8-10 years. This age group was targeted due to the participants being old enough to understand instruction but still being pre-adolescent (20), therefore reducing the chance of an increase in sex hormone concentration and a resulting increase in muscle mass (24). Participants were ineligible if they were currently engaged in regular RT or had extensive experience in RT. They were also ineligible if they had: a pathological condition or disability which affects movement (e.g. cerebral palsy or dyspraxia), a behavioural or neuropsychological condition (e.g. autism or attention deficit hyperactivity disorder) or a physical injury preventing testing or training. Participants were only included if they were classified as either overweight/obese (37) (the cut off points are described below) or did not meet the MVPA guidelines (12) (defined as 'inactive' in this study) as evaluated during the first assessment session. Informed written consent was provided by participants and parents.

Participants

Twelve participants (7 males, 5 females) were recruited. All participants were classified as 'inactive' (6) and/or were classified as overweight or obese (37). The participants were quasi-randomly allocated to the experimental group (EG, 3 males, 3 females) or control group (CG, 4 males, 2 females) based on training day availability.

Procedure

Following completion of health questionnaires, baseline testing on all participants was conducted where strength, FMS, weight status and physical self-perceptions were assessed. All assessments were completed by trained research assistants. Measurements were completed on the same day, using the same instruments at each time point and in the same order. Participants completed the questionnaires before physical assessments to prevent the actual process of assessment influencing their responses. Following these sessions, accelerometers were provided to be worn for 7 days. Follow up tests were subsequently completed the week following the intervention. Attendance was recorded and compliance calculated as the average number of sessions attended by all participants.

Assessments

Strength

An isometric mid-thigh pull (IMTP, custom built rig, Pasco force plates) was used to assess peak force with a previously reported protocol involving a standardised warm up, standard set up position and maximal pull over two trials (142). The highest peak force in Newtons and peak force relative to body mass were used for analysis. Within- and between-session measures of absolute and relative peak force were previously reported to be reliable ($CV \leq 9.4\%$, $ICC \geq 0.87$) (142) and in a recent study using the same equipment, although in an adult population, similar reliability is evident ($CV \leq 9.8\%$, $ICC \geq 0.91$) (153) and therefore this was deemed acceptable.

Fundamental Movement Skills

To assess FMS, the Canadian Agility and Movement Skills Assessment (CAMSA) was conducted (131) with the time required to complete the course recorded and the quality of each skill scored as prescribed in a specified checklist (including items such as “body and feet are aligned sideways” and “correct step-hop foot pattern when skipping”) (131). The total score was quantified as sum of skill and time scores. Evidence for test–retest reliability for completion time was excellent (ICC = 0.82-0.84) and for the skill score, it was moderate to substantial (ICC = 0.46-0.74) (131). Although in this study, intra-rater reliability was not assessed for the time or total score in this study, for both the EG and CG (12 participants, pre-intervention data), for the skill score, it was excellent (ICC = 0.85).

Weight Status

Stretch stature (Seca Leicester stadiometer) and body mass (Seca 813) were assessed to the nearest 0.1cm and 0.1kg respectively (117). Body Mass Index (BMI) was calculated and BMI Z-scores for age and gender (standard deviation score) which are measures of relative weight adjusted for child age and sex (35). This was calculated using the Cole LMS method and UK 1990 reference data based on 37,700 children, with an age range of 23 weeks gestation to 23 years (36). BMI related weight status was classified as: healthy weight = BMI Z-score <1.04; overweight = BMI Z-score 1.04–1.63; obesity = BMI Z-score ≥1.64 (37).

To assess body fatness, four skinfolds (tricep, bicep, subscapular and supraspinale) were taken by a Level 1 ISAK accredited anthropometrist (117). This method has been used previously with children (118). Girth measurements were also taken for the waist, hips, and right upper arm (117). The Technical Error or Measurement (TEM) acceptable by ISAK standards for skinfolds is <7.5% and for girths is <1.5% and the assessor’s TEM for these measures were <3% and <0.6% respectively, although in an adult population. However, this was deemed acceptable.

Physical Self-Perceptions

The CY-PSPP (113) was used to assess the participants' physical self-perceptions. This test assesses 6 different dimensions of self-concept: sport competence, physical condition, body attractiveness, strength competence, physical self-worth, and global self-worth (113). This questionnaire has been validated with children aged between 8-12 years (114). Perceived body attractiveness was not a key outcome measure and was removed from the questionnaire.

Physical Activity

PA was monitored with an ActiGraph GT3X+ accelerometer for 7 days before and after the intervention. Accelerometers were set to record at a 30Hz sampling frequency (154). Participants were instructed to wear the monitor at all time times on the right hip, except during water-submerged activities, during contact sports, or during sleep. Raw data was downloaded on the ActiLife 6.1 software as activity counts at 10 second intervals. Valid wear time was defined as a minimum of 4 full days of recorded accelerometer data (including at least 1 weekend day), with a full day consisting of a total 10 hour wear time (155). A 60-s epoch was used and non-wear time was defined as strings of consecutive zeros lasting 60 min or more (156). The accelerometer output is in counts per minute (cpm). Evenson cut points (123) were used to define time spent being sedentary (≤ 100 cpm) and time spent in MVPA (≥ 2296 cpm). Extra activity was recorded via a physical activity diary, including estimated intensity of the activity, and additional MVPA minutes were added for participants who had performed activities while not wearing the accelerometer (e.g. swimming).

Treatment conditions

The CG was asked to refrain from any RT and maintain their normal PA for the study period. The experimental group participated in a progressive RT programme delivered after school at the University of Dundee twice a week for 10 weeks in addition to their normal activity. Qualified strength and conditioning coaches delivered the sessions, with a coach to participant ratio of 1:3. The session content is

shown in table 1. The range of sets and reps followed recommendation by the UKSCA for a youth beginner (11) and a warm up and cool down was completed (20). The participants initially were to complete 8 repetitions but as the loading increased, this was reduced to 6. There were 4 key exercises (Table 1) with variable core strength exercises and a 'hanging challenge' to finish. The use of body weight and free weights were included as they provide a full body movement to challenge major muscle groups and control of body mass in a variety of push, pull, squat and lunge movements to develop foundational strength (127). The exercises outside of the key exercises were varied and were sometimes a choice of the participant to encourage engagement. Rest between sets and exercises was 60 to 120 seconds (20) and the initial load was the lightest available (broomstick or 5kg bar (with 2.5kg plates for deadlifts)). This load progressed by 5-10% once the coach deemed the participant competent at the exercise and the load appeared insufficient to provide overload (20). Load progression during the intervention was recorded. The session duration was 45 minutes.

Table 1 Resistance training programme

Exercise	Sets/Reps
Warm up – a variety of active games, overhead broom stick squat (plus 1 warm up set of each exercise)	5 minutes
<i>Key exercise 1- Deadlift</i>	2 x 6-8
<i>Key exercise 2- Push Press/TRX row</i>	2 x 6-8 (alternate push/pull each session)
<i>Key exercise 3- Back Squat</i>	2 x 6-8
<i>Key exercise 4- Walking lunge/overhead lunge/side lunge</i>	2 x 6-8 (each leg)
Front plank/dead bugs/hollow hold	Variable depending on the exercise.
Hanging challenge – hang from a pull up bar.	Maximum hang time
Cool down – stretch of major muscle groups	5 minutes

Feedback Session

A feedback session was conducted and recorded with the parents (n = 5) and children (n = 5) from the EG, following the intervention. The key theme explored was whether the parents and the children felt there were benefits (to the child) from taking part in the intervention.

Data analysis

Data analysis for the quantitative measures was undertaken using the Statistical Package for the Social Sciences (SPSS, version 22, SPSS Inc., Chicago, Ill, USA) with differences between treatment groups being considered statistically significant at $P < 0.05$. Using the Shapiro-Wilk test, studentized residuals were assessed for normality ($P > 0.05$) and Levene's Test was used to assess homogeneity of variance ($P > 0.05$). Differences between groups at baseline were tested using independent samples t-tests. A mixed ANOVA with repeated measures was conducted to examine the effect of the intervention between groups, over time. Hedges' g was used to assess the differences in changes scores between the EG and CG (pre and post intervention). Effect sizes were defined as small (0.20-0.49), medium (0.50-0.79) and large (>0.80) (Cohen, 1988). All data are presented as mean ($\pm$ SD). Recommended sample sizes were calculated using G-Power following the primary analyses to determine the sample size required to detect the effect at the chosen significance level (157)

RESULTS

Table 2 shows the baseline characteristics of the sample. The age of the sample was 8.9 ± 1.0 years. All participants were classified as either overweight/obese (n=11) and/or inactive (n=10), noting that there was not sufficient wear time for two of the participants to assess activity levels (although they were both classified as overweight/obese). Mean sessions attended was 79% (ranging from 70-90%) and, removing missed sessions due to school holidays (4 sessions), the mean attendance was 93% (ranging from 90-100%). None of the participants withdrew from the study. There were no reported training injuries or excessive muscle soreness at any stage. There were no significant differences between the groups at baseline across all measures (Table 2).

Table 2 Baseline characteristics

Variable	Experimental Group (n = 6) (mean±sd)	Control Group (n = 6) (mean±sd)
Age (yrs)	8.7±1	9.2±1
Males (n)	3	4
Females (n)	3	2
Stretch stature (cm)	143.3±5.3	140.8±5.8
Body mass (kg)	50.5±11.2	40.3±6.4
BMI (kg/m ²)	24.4±4.0	20.3±2.5
BMI Z-score	2.54±0.61	1.50±0.93
Overweight (n)	0	2 (33%)
Obese (n)	6 (100%)	3 (50%)
Inactive (n)	5 (100%)	5 (100%)
Average daily MVPA (mins)	38.2±11.6 (n=5)	37.9±6.6 (n=5)

Note - baseline physical activity data was collected from 10 out of 12 participants. No statistically significant differences between groups ($P<0.05$).

Table 3 shows the pre and post intervention data for all outcomes for the EG and CG alongside the ANOVA data and associated effect sizes. Although baseline measures of MVPA were collected, statistical analysis was not possible as only data from three participants in each group was obtained.

Table 3 Changes in outcomes for EG and CG pre and post intervention

Outcome	EG (n=6) mean±sd (range)			CG (n=6) mean±sd (range)			Effects (group x time)		
	Pre	Post	Change	Pre	Post	Change	F	P	Effect size (Hedges' g)
The Self									
CY-PSPP total score	88.8±16.5 (57.0-101.0)	89.7±10.0 (72.0-103.0)	0.8±8.4	90.5±22.0 (60.0-120.0)	91.8±17.9 (74.0-120.0)	1.3±6.8	0.011	0.919	0.031
Perceived strength	19.8±2.9 (17.0-24.0)	19.2±3.8 (16.0-24.0)	-0.7±0.9	18.5±6.1 (9.0-24.0)	18.8±4.7 (12.0-24.0)	0.3±2.8	0.570	0.468	-0.214
Physical self-worth	20.0±4.5 (12.0-24.0)	19.8±2.7 (16.0-24.0)	-1.2±3.1	18.8±5.4 (12.0-24.0)	18.5±4.7 (12.0-24.0)	-0.3±2.1	0.254	0.625	-0.201
Global self-worth	18.2±4.7 (9.0-22.0)	20.0±3.0 (15.0-23.0)	1.8±3.3	20.3±4.7 (12.0-24.0)	21.0±5.1 (11.0-24.0)	0.2±0.7	1.196	0.300	0.367
Sport competence	15.3±3.4 (11.0-19.0)	15.5±4.0 (10.0-19.0)	0.2±1.1	16.5±6.1 (8.0-24.0)	18.3±4.8 (12.0-24.0)	1.8±2.0	2.809	0.125	-0.345
Physical condition	15.5±4.8 (7.0-21.0)	16.2±3 (10.0-20.0)	0.7±4.5	15.8±6.2 (9.0-24.0)	15.2±5.3 (10.0-24.0)	-0.7±4.8	0.206	0.659	0.275
FMS									
CAMSA total score	13.2±4.2 (9.0-19.0)	17.0±4.2 (12.0-22.0)	3.8±1.1	16.8±3.1 (14.0-22.0)	17.5±2.6 (14.0-20.0)	0.7±2.2	8.318	0.016*	0.830
CAMSA time score	4.2±2.9 (1.0-9.0)	6.5±2.9 (3.0-10.0)	2.3±1.1	7.5±2.1 (5.0-11.0)	8±2.1 (6.0-10.0)	1.0±1.7	2.105	0.177	0.498
CAMSA skill score	9.5±1.9 (7.0-12.0)	11.0±1.8 (8.0-13.0)	1.5±0.8	10.0±0.9 (9.0-11.0)	10.0±1.3 (9.0-12.0)	0.0±1.1	5.870	0.036*	0.895
Weight status									
Stretch stature (cm)	143.3±5.3 (138.4-150.4)	145.5±5.5 (140.3-153.2)	2.2±0.3	140.8±5.8 (132.5-147.1)	142.0±6.1 (133-148.9)	1.3±0.4	16.696	0.002*	0.150
Body mass (kg)	50.5±11.2 (40.4-71.2)	51.8±10.7 (42.5-71.7)	1.3±0.8	40.3±6.4 (29.4-47.9)	41.0±6.4 (29.7-47.1)	0.8±0.9	0.863	0.375	0.056
BMI (kg/m ²)	24.4±4.0 (21.5-31.6)	24.3±3.5 (21.4-30.6)	-0.1±0.6	20.3±2.5 (15.9-23.5)	20.2±2.4 (15.6-22.3)	-0.1±0.5	0.045	0.837	0.025
BMI Z-score	2.54±0.61 (2.09-3.70)	2.49±0.56 (2.03 – 3.58)	-0.04±0.09	1.50±0.93 (-0.24-2.36)	1.47±0.93 (-0.38-2.19)	-0.0±0.1	0.010	0.921	-0.024
Skinfolds (mm)	89.6±21.8 (66.0-122.4)	86.0±17.6 (68.1-108.0)	-3.7±7.0	65.2±22.6 (28.0-95.4)	65.4±21.4 (26.4-89.0)	0.0±4.9	0.917	0.361	0.169
Waist circumference (cm)	80.8±11.8 (68.0-103.0)	80.4±9.9 (72.0-100.0)	-0.3±2.4	69.2±5.2 (60.2-75.5)	70.0±4.5 (57.5-75.0)	0.8±1.8	0.665	0.434	0.122
Hip circumference (cm)	90.3±7.3 (83.0-103.0)	90.4±7.8 (83.0-104.5)	0.2±1.7	81.0±6.7 (70.0-88.0)	81.4±6.4 (69.5 -86.5)	0.4±1.6	0.037	0.851	0.026
Arm circumference (cm)	26.7±2.4 (23.0-30.2)	26.4±1.9 (23.4-28.5)	-0.3±0.9	23.4±2.8 (19.0-27.8)	24.4±2.8 (19.5-27.5)	1.0±1.3	3.257	0.101	0.500

Strength									
Maximal strength (N)	1007.8±255.7 (737.0-1455.0)	1088.7±263.2 (812.0-1471.0)	80.8±67.6	862.7±118.8 (675.0-975.0)	872.2±104.5 (710.0-998.0)	9.5±74.8	2.501	0.145	0.329
Relative strength (N.kg ⁻²)	19.9±1.4 (18.0-22.0)	21.0±2.3 (19.0-25.0)	1.1±1.3	21.7±2.9 (18.0-26.0)	20.9±1.9 (19.0-24.0)	-0.8±3.0	1.605	0.234	0.825
MVPA									
Average daily MVPA (mins)	38.2±11.6 (30-54)	37.3±13.4 (22-47)(n=3)	-4.7±4.9	37.9±6.6 (30-46)	30.3±10.0 (19-38)(n=3)	-6.6±4.6	/	/	/

* = P<0.05

Hedges' g = the difference in change scores between the EG and CG (pre and post intervention).

Abbreviations: CY-PSPP = Children and Youth Physical Self-Perception Profile, CAMSA = Canadian Agility and Movement Skills Assessment

Intervention effects

The studentized residuals were normally distributed ($P > 0.05$) and Levene's Test to assess homogeneity of variance was also not significant ($P > 0.05$) for all outcomes and therefore parametric analysis was acceptable. From the ANOVA analysis, there were significant time x group interactions for CAMSA total ($P = 0.016$), CAMSA skill score ($P = 0.036$) and stretch stature ($P = 0.002$) with the EG displaying larger changes than the CG. This demonstrated a positive impact of the RT intervention on FMS. Where there were not significant time x group interactions, the significant main effects for time were: stretch stature ($P < 0.001$), and body mass ($P = 0.004$) and the significant main effects for group were: BMI ($P = 0.048$), BMI Z-score ($P = 0.046$) and hip circumference ($P = 0.048$).

While not statistically significant, there were large, positive effect sizes for CAMSA total score (Hedges' $g = 0.830$, $P = 0.138$), CAMSA skill score (Hedges' $g = 0.895$, $P = 0.112$) and relative strength (Hedges' $g = 0.825$, $P = 0.140$). There was a medium positive effect size for arm circumference (a decrease in the EG but an increase in the CG) (Hedges' $g = 0.500$, $P = 0.357$). All other effect sizes were negligible or small. A post hoc power analysis revealed that an n of between 4-70 (on outcomes where an effect size of ≥ 0.2 was evident) would be needed to obtain statistical power at the recommended 0.80 level (158).

Although statistical analysis was not conducted on the MVPA data, it was apparent that there was a trend towards a decrease in MVPA, with a larger decrease evident for the CG. In exploring the individual response data where sufficient data was attained, in the experimental group, two out of the three participants displayed decreases in MVPA (13% and 26%) and the third participant displayed an increase of 2.4%. In the CG, all three participants displayed decreases in MVPA (4.2%, 17% and 35.6%).

Feedback Session

Children and parents expressed positive changes with regard to 'the self' including: feeling positive to keep progressing, improved confidence and a sense of achievement. Additionally, comments were made that might support an impact of RT on PA levels with one child stating that they were encouraged to try other activities

and another child identifying that they had gained strength which had made running easier.

DISCUSSION

The aim of this study was to investigate the impact of RT on strength, correlates of PA (weight status, FMS and 'the self') and MVPA. There was a statistically significant interaction for group x time for the FMS outcomes of CAMSA skill score, and total score, with large effect sizes for some FMS outcomes. There were also small to large effect sizes for strength, a medium effect size for weight status and small effect sizes for physical self-perceptions. There were no statistically significant findings for all other outcomes and there were not sufficient data to statistically analyse the impact on MVPA, however individual response data suggested a trend towards a decrease in MVPA, more so in the CG. This pilot study shows that there are positive effects of RT on specific correlates of PA in youth and potentially also on strength, although further research would be required to substantiate this. Therefore in part, these findings support the UKSCA (11) and NSCA's (20) position statements on youth RT that both report that RT may have a positive impact on FMS, strength, weight status, and 'the self'.

Strength

Although there were no statistically significant findings demonstrating differences in the changes over time, between the groups, there was a large positive effect size found for relative strength ($g = 0.825$, $P = 0.140$) and a small, positive effect size for maximum strength ($g = 0.329$, $P = 0.540$). Importantly for an overweight/obese population, an improvement in strength promotes engagement in daily activities, physical activity and subsequently improves their health-related quality of life (159). Therefore, an increase in relative strength is an important outcome for this participant group and the large effect size is a potentially relevant finding.

Previous studies have shown an increase in strength following a RT intervention in overweight and obese youth (47, 160) despite variable protocols used to measure strength and inconsistent intervention design. An improvement in strength, particularly in prepubescent participants, has been attributed to neural factors rather

than hypertrophy (161) which is in support of the PIT model regarding the association between strength and FMS (16) and additionally could explain the FMS findings in the present study, which are detailed below.

FMS

CAMSA skill and total scores significantly increased in the EG in comparison to the CG over time ($P = 0.036$ and $P = 0.016$ respectively), although this was not the case for CAMSA time score. It is important to note that time score did not decrease so the participants did not compromise the speed of movement for quality. When examining the effect sizes, there was also found to be a large effect of the intervention on the CAMSA skill score ($g = 0.895$) and the total score ($g = 0.830$) (although time score is accounted for in the total score). An explanation for these positive findings could be that neural adaptations (changes in motor unit coordination, firing and recruitment) occurred as a result of RT (162), and since they are essential for optimal movement, were manifested in changes in FMS. This also supports the hypothesis that strength could be an underlying mechanism that would explain the change in FMS, paralleling the observed trend of increased relative strength.

Our current findings suggest that RT has a positive effect on 'process outcomes' of FMS (i.e. skill score) which, as far as we are aware has not been previously evaluated in the literature. This would imply that a RT intervention has a positive impact on the quality of movement. Improved FMS competence is thought to accompany increased PA (163) and recent research has reported associations between process assessments of FMS and PA levels (60, 151). Therefore, if RT has a positive impact on FMS as is suggested by the current study, it is hypothesised that this could have a positive effect on PA levels, however, further work is needed to substantiate this.

Weight status

Although there were no significant time x group interactions, the statistically significant positive changes over time for stretch stature ($P < 0.001$), and body mass ($P = 0.004$) are logical findings due to maturation. The statistically significant changes in stretch stature in the EG, in comparison to the CG over time ($P = 0.002$)

may have an influence on the group differences in BMI and BMI Z-score, however, effect sizes were negligible. Despite no statistically significant changes in weight status outcomes in the EG, in comparison to the CG, over time the medium positive effect size for arm circumference ($g = 0.500$) is difficult to interpret due to no significant changes in skinfolds. This finding could possibly be due to an increase in skeletal muscle mass and resulting increase in basal metabolic rate (38). However, there is mixed evidence with regards to whether youth may experience increases in muscle mass following RT, most likely due to inadequate levels of circulating testosterone (20); this may explain why there were no effects on the majority of weight status outcomes in the present study. Additionally, taking part in an active intervention was not sufficient to increase overall energy expenditure to elicit a change in weight status outcomes. This emphasises the importance of including dietary measures in further research.

A previous study involving a similar population reported a significant decrease in body fat percentage and increase in lean body mass (144), which were findings not observed in the present study. However, there was a larger sample size, a DEXA scan was used as the measurement tool and the participants trained three times a week. Although overall the evidence to support a positive effect of RT on weight status is not compelling, there is some evidence from the findings to support a positive effect. Consequently, a larger scale study of longer duration would be recommended to investigate this in more depth, in particular as there is a trend of decreasing skinfolds measurements in the EG.

'The self'

There were no statistically significant changes in CY-PSPP score in the EG, in comparison to the CG. From the effect size data, there were small positive effect sizes for perceived physical condition ($g = 0.275$) and global self-worth ($g = 0.367$), but small negative effect sizes for perceived strength ($g = -0.214$), sport competence ($g = -0.345$) and physical self-worth ($g = -0.201$). With negligible to small effect sizes, these findings are unlikely to represent an important change and additionally are in conflict with some of the feedback session comments. This might suggest that although the measurement tool was previously validated with a similar age group (114), this might have had an impact on the findings due to reported developmental

differences (164). Similar studies using the same assessment tool reported significant findings (30, 136), which is in conflict with the findings of the current study. However, the participants were older, the studies involved larger sample sizes, and the interventions were longer duration.

Physical Activity

Although statistical analysis was not conducted on the MVPA data, for those met the required wear time, five out of the six participants displayed decreases in MVPA, and therefore this trend is worthy of discussion. On the whole, this decrease could be due to a multitude of factors, including the weather (165), the school Physical Education curriculum (166), or that there was initial response bias (167). With the CG decreasing by more, this could suggest that the RT had a positive impact in reducing the decline which could be important considering the reported decline of PA from childhood to adolescence (15).

Feedback Session

While the feedback session was not part of the data reported herein, anecdotally, the researchers learned that, based on the comments from both parents and children, there are potential positive impacts on 'the self' that may not have been evidenced in the questionnaire. Future investigations should include specific qualitative methodologies to uncover these possibilities. These positive comments imply the possible sustainability of such a programme and are in agreement with a previous meta-analysis (85). A specific comment made regarding a child feeling confident enough to try other activities, also supports the hypothesis that the RT programme could indirectly impact on PA levels.

Limitations

The power analysis indicated that the study was adequately powered for the CAMSA total score and speed score (required $n = 4$ and 6 respectively), however it was underpowered to detect small between group differences for many outcomes. This pilot study makes a unique contribution however by providing the effect sizes needed to inform a definitive RCT to investigate this topic further. Regarding recruitment, it could be difficult for parents to acknowledge that their child may be inactive and/or overweight/obese and therefore they may be less likely to see the need for their child

to be involved (168). Hence, it may be beneficial to recruit via a clinical pathway for this population in future definitive RCT's.

Regarding the data, although not statistically different at baseline, there appears to be large differences between the groups for some of the measures and this should be acknowledged when interpreting the results. Specifically for the measure of 'the self', it should be noted that questionnaires administered to youth may not be understood by the participants, particularly due to the young age (pre-adolescent) (169) and therefore this may present a limitation for the current study. Additionally, future research should consider a measure of maturation status. This is due to variability in maturation and the implications this might have on the findings, accounting for an increased responsiveness to training which may have an impact on the magnitude of effects (26). Finally, unfortunately there was not sufficient post intervention data collected for MVPA and it is apparent that significant emphasis on the importance of sufficient wear time and clear instructions are crucial. However, research has reported the difficulties of compliance with accelerometer wear time in children (170) but suggests some ways to increase this, such as rewards, social conformity and wear time reminders (171), which could be implemented in future studies to increase compliance.

Although the intervention was 10 weeks in duration, it took a significant amount of time for the children to learn the exercises and therefore a familiarisation period would be recommended. Additionally, while participants were asked to maintain their normal PA and dietary patterns over the study period, it is not possible to ascertain if this was the case. Our study did not include a long-term follow-up and it is therefore unknown whether any changes in outcomes persisted when the training stimulus was withdrawn, and longer-term studies are needed to determine if any benefits from RT are maintained, if the participants remain engaged and/or have increased PA levels.

Conclusion

In summary, this study demonstrated that a 10 week RT intervention has a positive effect on FMS and strength. Effect sizes suggest there may also be an impact on weight status and 'the self'. Overall, this pilot study provides evidence to support the

effectiveness and feasibility of RT as a mode of PA for overweight/obese and/or inactive youth. Furthermore, the study offers both guidance for future intervention design, for a full RCT, and programme delivery. To build on these findings, a larger scale study could provide useful evidence to support the development of RT interventions for inactive and/or overweight/obese children to not only develop the identified correlates of PA but ultimately increase PA levels and in the longer term have a positive effect on health and well-being.

CHAPTER 5: Discussion

The purpose of this thesis was to explore the impact of resistance training (RT) on strength, correlates of physical activity and physical activity levels in youth.

Subsequently, there were two specified research questions:

1. *Does resistance training have an impact on weight status, fundamental movement skills and the self in youth?*
2. *Does resistance training have an impact on physical activity levels (MVPA) in youth?*

As mentioned in the introduction, although not presented as a specific research question, strength was included as a key outcome due to being identified as a possible mechanism underlying a direct increase in MVPA and/or a change in the identified correlates of PA as a result of RT.

To address these research questions, three systematic reviews and meta-analyses were first conducted, enabling a thorough examination of the literature. Then, following the MRC framework (87), two feasibility studies were carried out to inform the development of a pilot study, which was then conducted. These processes ensured that the aim of the thesis was investigated in a robust manner to provide a clear contribution to the field. Regarding the main findings, there was some evidence to suggest that RT has a positive impact on the correlates of PA and on strength, which was apparent through the results of meta-analyses and the pilot study. Additionally, it was evident that RT is a feasible mode of activity for an inactive and/or overweight/obese youth population which is a key outcome to inform future PA intervention development. Unfortunately, it was not possible to ascertain a direct impact of RT on MVPA and therefore it was proposed that further research would be required to substantiate this.

5.1 Research question 1

Previous research reported that RT has a positive impact on weight status, FMS and ‘the self’ in youth (11, 20). However, the magnitude of this effect had not been

recently explored, if explored at all. Following an initial review of the literature, there was limited evidence that examined the impact of RT alone on these correlates of PA and some of this was more than a decade old. Therefore, this provided the rationale for conducting the three systematic reviews and meta-analyses to investigate the effect of RT on weight status, FMS and 'the self' in youth.

Overall, the findings of the systematic reviews and meta-analysis in part supported the hypothesis that RT has a positive impact on the correlates of PA. However, it should be noted that there were not statistically significant effect sizes evident for all of the identified outcomes and furthermore, across all reviews, there was large variability between studies and reflection of only a small body of published work. Moreover, as the three reviews were published, this shows a valuable contribution to knowledge. It was evident from these studies that although there were promising findings, there was scope to conduct further research and therefore this provided a rationale to conduct a controlled trial to investigate the effect of RT on the correlates of PA. The evidence from both the systematic reviews and the pilot study are discussed below.

5.1.1 Weight status

Weight status was a key outcome not only due to being associated with PA levels (43-46) but also because previous research alluded to a positive impact of RT on weight status (48-50). It was reported that engagement of youth in PA is a fundamental component in the prevention of obesity (10). Therefore, if RT has a positive effect on weight status, this could be beneficial for the prevention and treatment of obesity.

The findings from the meta-analysis suggested that RT has a positive effect on body fat percentage and skinfolds in youth which is in support of the UKSCA's (11) and NSCA's (20) position statements. It is important to note that this meta-analysis was the first to include healthy weight and overweight/obese participants taking part in RT only interventions, which was important to identify the impact of RT not only as a treatment for obesity but also as a prevention. The pilot study in this thesis included both overweight/obese and inactive participants rather than solely overweight/obese

participants for this reason, but additionally to address the implications of inactivity irrespective of weight status.

Contrary to the review level evidence, there were no statistically significant findings in the pilot study to support a positive impact of RT on weight status. Possible reasons for this and recommendations for further research are discussed in Chapter 4. However, it is important to acknowledge the excellent attendance figures and feedback session information which suggest that RT, as a mode of activity, is feasible for an inactive and/or overweight/obese youth population.

5.1.2 Fundamental movement skills

To address the second identified correlate, previous research supported a strong association between FMS and PA (59). The PIT model also alludes to an association between muscular strength and FMS (16) with support from systematic reviews that reported a positive impact of RT on FMS (62-64). This is further reinforced by the component of the current UK PA guidelines that recommends activity to develop both movement skills and muscle strength (12), which suggests that FMS and strength are in synergy.

From the systematic review and meta-analysis conducted as part of this thesis, there were statistically significant effect sizes evident for the effect of RT on all of the FMS outcomes, which is consistent with the UKSCA's (11) and NSCA's (20) position statements. However, the meta-analysis included both inactive and active youth, although the majority of studies included participants who were involved in a specific sport, and therefore this suggested further research including an inactive youth population would be beneficial. Additionally, all of the measures in studies included in this meta-analysis were product-oriented with quality of movement not being assessed, which when investigating FMS in inactive individuals, is an important consideration (58).

Despite being a pilot study, the findings presented in Chapter 4 demonstrated a statistically significant impact of RT on FMS, which complements the findings from

the meta-analysis. A measurement tool was used in the pilot study that was not included in any of the studies in the meta-analysis and implemented both a product and process oriented component (131). It was also undertaken with a population who were inactive and/or overweight/obese. Low levels of FMS competence have been reported in youth and furthermore, have been shown to be associated with low levels of PA (172). The importance of FMS for PA of youth is emphasised by a recent BASES Expert Statement on the topic (173). In relation to RT, in the statement, it was reported that FMS interventions should include a structured component, which may allude to a benefit of RT, however it was stated that the content should be specifically aimed at developing a broad range of FMS (173). In the pilot study of this thesis there were statistically significant improvements in FMS despite not including specific activity with the aim of improving FMS. The potential positive impact of RT on FMS combined with a parallel trend for an increase in strength evident in the pilot study, lends further support to the PIT model which identifies an association between strength and FMS (16). The results from the pilot study also support the hypothesis of strength being a possible underlying mechanism that explains the effect of RT on FMS and furthermore, highlights the important neuromuscular developments as a result of RT.

As it is clear that the development of FMS is essential to maximise the potential of a physically active childhood and beyond (59), using RT as an intervention strategy could provide a successful mode of activity. This could not only appeal to certain youth populations but it also ensures that a component of the PA guidelines is being met, both through activity to develop movement skills as well as muscle and bone strength (12).

5.1.3 The self

To address the final correlate that was investigated, review level evidence provided support for a positive relationship between PA and constructs relating to ‘the self’ in youth (66, 67, 75, 76). There was also a reported association between muscular fitness and physical self-perceptions, overall physical self-worth and global self-esteem (77). Out of the three identified correlates, ‘the self’ had the least amount of

published research on the topic, and although there was evidence of an association between muscular fitness and ‘the self’ (77), it remained unclear whether there was a direct effect of RT on ‘the self’, and therefore it was a fundamental outcome to examine further.

The systematic review and meta-analysis was the first to synthesise research on the effects of isolated RT interventions on ‘the self’, however only four data sets were included in the analysis. Despite few included studies, RT was found to have a positive effect on: resistance training self-efficacy, perceived physical strength, physical self-worth and global self-worth, which complements the UKSCA’s and NSCA’s position statements (11, 20). However, due to a limited number of studies, there was need for further research to investigate this area in more detail. In the pilot study of the thesis, there were no statistically significant findings for the impact of RT on ‘the self’, and limitations of the study and recommendations for future research were discussed in Chapter 4. Despite the lack of statistically significant findings, the feedback session information and general comments indicated positive experiences.

These positive experiences could be explained by Self Determination Theory (SDT) (145) and this should be considered when exploring the impact of RT on ‘the self’. It has been reported that motivation to take part in physical activity is positive when the form of activity is autonomous and there is competence satisfaction and intrinsic motives (174). In support of this, it was stated in SDT that when a person is intrinsically motivated, they experience feelings of enjoyment and personal accomplishment (175). Furthermore it has been reported specifically in youth that autonomous motivation positively predicts greater levels of physical activity and positive attitudes towards physical activity (176). The intervention in the pilot study of this thesis offered the participants the opportunity to develop competence in new skills through an autonomous and supportive approach, which could explain why the participants were compliant. This therefore emphasised the importance of considering SDT when exploring the impact of RT on the self.

5.2 Research question 2

To address the second research question and investigate a possible direct impact of RT on MVPA in youth, an initial literature search resulted in only two relevant studies being identified (32, 33). Whilst providing promising results, these studies only demonstrated significant findings in males and did not substantially explore the potential underlying mechanisms of the effect of RT on MVPA, although in both studies there were significant increases in strength. Unfortunately, the results of the pilot study of this thesis were inconclusive due to insufficient data collected for MVPA, despite showing a trend towards a decrease. The possible reasons for this are discussed in Chapter 4 although ultimately it is still unknown if there is a direct impact of RT on MVPA. The reported increase in relative strength evident in the pilot study is an important finding worth highlighting in relation to MVPA and strength as a possible mechanism. The PIT model suggests an association between muscle strength and MVPA (16) and therefore it could be proposed that this improvement in strength could indirectly support the hypothesis of an impact of RT on MVPA. Ultimately though, the research question still remains unanswered.

5.3 A working model

The work presented in the current thesis provides evidence to develop a conceptual model, that in, part supports some of the proposed ideas outlined in the PIT model (16) but also proposes hypotheses for further research. The Pediatric Inactivity Triad (PIT) as previously mentioned in Chapter 1, involves three distinct but inter-related components: 1) exercise deficit disorder (EDD), 2) paediatric dynapenia, and 3) physical illiteracy (see Figure 1)(16). This conceptual model proposes that these three elements interact and ultimately, through interventions designed to have a positive impact on these components, there is the increased likelihood of maintaining a healthy level of PA into adulthood.

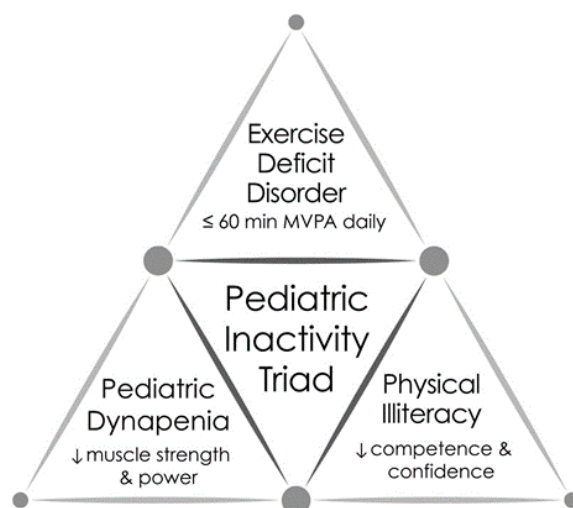


Figure 1- Pediatric Inactivity Triad (PIT)(16) (with permission from Current Sports Medicine Reports).

In the application of this model regarding the development of physical activity interventions, Faigenbaum *et al.*, identified that many interventions are focussed on increasing MVPA but that this might not be sustainable or have as much impact without consideration for the other two parts of the triad (16). For example, walking programmes that attempt to increase MVPA in youth overlook the critical importance of enhancing neuromuscular fitness and improving physical literacy (16). This is supported in part by the findings of this thesis regarding development of strength and FMS, but unfortunately, the association with MVPA could not be evaluated. A key point to note is that the PIT model does not take into account weight status, which is an important outcome to consider in inactive youth (45). Finally, the suggestion remains that by delivering interventions including activities that improve strength, movement competence and confidence, this could be an effective strategy to improve PA levels.

Based on the findings of the thesis and taking into consideration the concepts identified in the PIT model, the following model demonstrates how a RT intervention could have a positive impact on MVPA. In part, there is evidence to support this model although further research is required to provide evidence to support the whole concept.

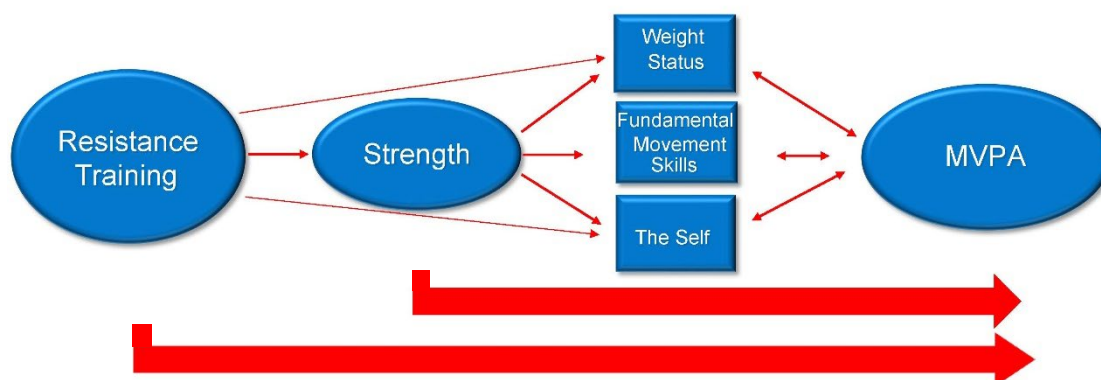


Figure 2 A conceptual model of the association between resistance training and MVPA.

This conceptual model proposes that RT could have a direct impact on MVPA (which has been demonstrated by two previous studies, (32, 33)) but additionally there could be a direct impact of strength on MVPA (supported by the PIT model). However, the findings of this thesis were not able to support this and therefore further research would be needed to validate this section of the model.

Other aspects of the model are however supported by findings in this thesis. There is an abundance of research, including the findings of this thesis, that shows that RT has a positive effect on strength (11, 20). Additionally, RT has been shown to have a positive impact on the identified correlates of PA: weight status, FMS and 'the self'. The model identifies that an underlying mechanism of a positive impact of RT on the correlates could be strength. This could be demonstrated by a) a possible increase in lean muscle tissue that would have an effect on weight status, b) neuromuscular developments, which would have an effect on FMS (which was strongly alluded to in the thesis findings), and c) maximal strength values, which could have an effect on 'the self'. Furthermore, the model takes into consideration that although strength is a possible mechanism underlying the impact of RT on weight status and 'the self', there may be additional factors that could explain this effect.

Moving across the model, a positive impact of RT on the correlates of PA could result in a sequential positive impact on MVPA. Ultimately this would suggest that the correlates mediate the effect between RT and MVPA. Finally, the arrows between the correlates of PA and MVPA are bidirectional suggesting that if there

was an increase in MVPA, this could also have a positive impact on the identified correlates.

This conceptual model in Figure 2 details how RT could be an effective strategy to increase MVPA, although a key consideration is also whether RT is an appealing activity for youth. There was previous evidence to suggest why RT could be an effective mode of PA for overweight/obese children (81). Furthermore, Pescud *et al.*, identified that for overweight children, pleasant social interaction with peers and trainers were motivators for continuation of RT (82). This could explain the compliance and enjoyment reported by the participants involved in the pilot study of this thesis, which is crucial for successful intervention development, as enjoyment has been shown to mediate the effects of youth PA programmes (132).

With barriers for PA participation previously identified as: competitiveness, peer pressure and negative school experiences (78), ridicule of unfit or overweight children during vigorous activity, changing of clothes and lack of fun for school-based interventions (79), it would seem evident that RT as an alternative might have alleviated some of these issues. On the whole, even if this strategy did not lead to an increase in MVPA, it is an appealing activity in itself as detailed in Chapter 4, and is a key component of the current PA guidelines.

5.4 Strengths and limitations

There are several strengths of this thesis. The contribution this research makes to the literature and scientific community is demonstrated by several of the findings being published and presented to a range of audiences. The overall research question was novel and informed by a clear research gap. The systematic reviews informed the design of two feasibility studies and a pilot study. The feasibility studies were fundamental to the success of the pilot study and although small in participant numbers, as a pilot study, the process provided some statistically significant findings and sample size calculations to inform the development of a future definitive RCT. There were also some useful observations, feedback session information and excellent attendance figures to determine that a RT intervention would be a feasible PA option for the target population.

Regarding limitations, the systematic reviews were conducted in a comprehensive manner and although the Cochrane handbook guideline stating that it is acceptable that the initial screening of titles and abstracts is undertaken by only one person (177), 10% of titles and abstracts were screened by a second author. However, the Cochrane handbook guidelines do recommend that ideally two people should screen the titles and abstracts independently (177). Despite this, there were very strong levels of agreement calculated and therefore 10% was deemed acceptable.

Furthermore, regarding the outcomes examined, strength was not included in any of the reviews. Initially strength was not included as a key outcome as the focus was on the correlates of PA. Only at a later date when strength was identified as a possible mechanism was it then explored as an outcome. However, as reported in the summary of Chapter 2, 91% of the studies included in the systematic reviews reported an increase in strength so this supports the notion that it is plausible and logical that strength would increase as a result of a RT intervention. Concerning the feasibility studies, a more successful recruitment strategy may have prevented the need for a second feasibility study.

The pilot study in Chapter 4 provided effect sizes with which to determine adequate sample sizes for a future definitive RCT. While this was not within the scope of this thesis, this is an important contribution to further the work in this field and would be beneficial to ensure a rigorous examination of the research questions (87). The lack of MVPA data was disappointing and although research has reported the difficulties of compliance with accelerometer wear time in children (170) it was suggested that rewards, social conformity and wear time reminders (171) might have been beneficial to increase compliance. Additionally, it is important to note that a strict inclusion criteria was employed for wear time will have had an impact on the results. Reviews have concluded that objective measures, such as accelerometers provide an accurate, reliable, and practical objective measure of physical activity in children and adolescents (178, 179). Accelerometers are popular due to their ability to capture large amounts of data, and ease of administration, particularly in large studies (180) and therefore it would still be recommended to collect MVPA data using this method. It is also important to note that during the feasibility studies, data collection was not problematic. Finally, although feedback sessions were informative

in the development and evaluation of the intervention, more structure to the sessions and qualitative analysis would have been beneficial.

Considering the research findings in the context of strength and limitations enables practical applications to be suggested and recommendations for future research to be made.

5.5 Recommendations for future research and practice

Although there are promising findings from this thesis, further research would be beneficial to explore this topic in more detail as a full definitive RCT, and in particular, to evaluate the proposed conceptual model. It would be beneficial to update the systematic reviews in the future to add to the data with new literature, strengthen the meta-analyses findings and to inform the design of future intervention studies. In preparing for an intervention study, this thesis would suggest that a well-planned feasibility study is fundamental to ensure that a main trial is robust (87). Regarding specifics of a definitive RCT, a future study should be longer in duration, involve a larger sample size and include a valid and reliable measure of MVPA, taking into consideration the advice for compliance. To increase recruitment, a clinical pathway may be beneficial. Additionally, as previously mentioned, more investigation into the application of Self Determination Theory could provide a clearer understanding of the motivation of the youth taking part and could have a positive influence on intervention design. Furthermore, there are other factors (identified as correlates of PA) that could mediate the effect of RT on 'the self', which include psychological, behavioural, cultural/social and environmental factors and so in the context of RT, this is an area that could be explored in more detail in future research.

Although not possible due to limited sample size in the pilot study, correlations to explore whether those who improved in strength, also improved in the other areas should be included in the analysis of a definitive RCT. By implementing this, it would strengthen the proposed hypothesis of strength being the mechanism that explains the impact of RT on the identified correlates of PA. Finally, the model proposes a bidirectional relationship between the correlates of PA and MVPA and this could be explored in a study of longitudinal design.

From an applied perspective, for intervention design it would be recommended to develop relationships with local schools, parents and the community for recruitment purposes. Although there is evidence to support the benefits of RT for youth, it is important to ensure that interventions are appropriate and it is essential that the content is designed based on the recommendations from NSCA (20), UKSCA (11). Furthermore, when delivering RT to a youth group, it is paramount that the coaches are appropriately qualified and the environment is safe. In particular for an inactive and/or overweight population, having an understanding of the group and what engages them requires frequent reflection on coaching practice.

5.6 Conclusion

Overall, the findings of this thesis suggested that, in part, there is a positive impact of resistance training on correlates of physical activity in youth and this was evident through the process of systematic reviews and through conducting a pilot study. It was also apparent that a RT intervention is a feasible mode of activity for an inactive and/or overweight/obese youth population which is an important finding as this shows this group met part of the current physical activity guidelines through an RT programme. What is still unclear is whether taking part in a RT intervention could have a positive impact on MVPA, and this warrants further investigation. This thesis adds to the current literature by emphasising the importance of RT as a mode of activity for youth and makes further steps towards the development of an appropriate strategy to support children to increase and/or maintain physical activity participation that includes both strength-based activity and MVPA.

REFERENCES

1. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world. 2018 [updated 2018. Available from: <https://www.who.int/ncds/prevention/physical-activity/global-action-plan-2018-2030/en/>.
2. Faigenbaum AD, Best TM, MacDonald J, Myer GD, Straccioli A. Top 10 research questions related to exercise deficit disorder (EDD) in youth. *Res Q Exerc Sport*. 2014;85(3):297-307.
3. García-Hermoso A, Ezzatvar Y, Ramírez-Vélez R, Olloquequi J, Izquierdo M. Is device-measured vigorous physical activity associated with health-related outcomes in children and adolescents? A systematic review and meta-analysis. *J Sport Health Sci*. 2021;10(3):296-307.
4. Janssen I, Leblanc A. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act*. 2010;7:40.
5. Telama R, Yang X, Leskinen E, Kankaanpää A, Hirvensalo M, Tammelin T, et al. Tracking of physical activity from early childhood through youth into adulthood. *Med Sci Sports Exerc*. 2014;46(5):955-62.
6. World Health Organization. Global recommendations on physical activity for health. 2011 [Available from: <https://www.who.int/dietphysicalactivity/leaflet-physical-activity-recommendations.pdf?ua=1>.
7. Kyu HH, Bachman VF, Alexander LT, Mumford JE, Afshin A, Estep K, et al. Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ*. 2016;354:i3857.
8. World Health Organization. Obesity and overweight. 2020 [Available from: <https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight>.
9. McLean J, Dean L, Cheong C, K., Dougall I, Hinchcliffe S, Mirani K, et al. Scottish Health Survey. 2020 [Available from: <https://www.gov.scot/publications/scottish-health-survey-2018-volume-1-main-report/>.
10. Hills AP, Andersen LB, Byrne NM. Physical activity and obesity in children. *Br J Sports Med*. 2011;45(11):866-70.

11. Lloyd RS, Faigenbaum AD, Stone MH, Oliver JL, Jeffreys I, Moody JA. Position statement on youth resistance training: the 2014 International Consensus. *Br J Sports Med*. 2014;48:498-505.
12. Chief Medical Office. UK Chief Medical Officers' Physical Activity Guidelines. 2019 [Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/832868/uk-chief-medical-officers-physical-activity-guidelines.pdf.
13. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep*. 1985;100(2):126-31.
14. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR, Jr., Tudor-Locke C, et al. 2011 Compendium of Physical Activities: a second update of codes and MET values. *Med Sci Sports Exerc*. 2011;43(8):1575-81.
15. World Health Organization Regional Office for Europe. Health Behaviour in School-aged Children survey. 2016 [Available from: http://www.euro.who.int/_data/assets/pdf_file/0018/303480/HBSC-No.7_factsheet_Physical.pdf?ua=1.
16. Faigenbaum AD, Rebullido TR, MacDonald JP. Pediatric Inactivity Triad: A Risky PIT. *Curr Sports Med Rep*. 2018;17(2):45-7.
17. Aubert S, Barnes JD, Aguilar-Farias N, Cardon G, Chang CK, Delisle Nyström C, et al. Report Card Grades on the Physical Activity of Children and Youth Comparing 30 Very High Human Development Index Countries. *J Phys Act Health*. 2018;15(S2):S298-s314.
18. Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis LK, Fitzgerald JS, et al. European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2 779 165 Eurofit performances representing 30 countries. *Br J Sports Med*. 2018;52(22):1445.
19. Faigenbaum AD, MacDonald JP, Straccioli A, Rebullido TR. Making a strong case for prioritizing muscular fitness in youth physical activity guidelines. *Curr Sports Med Rep*. 2020;19(12):530-6.
20. Faigenbaum A, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M. Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res*. 2009;23:S60-S79.
21. Stratton G, Jones M, Fox KR, Tolfrey K, Harris J, Maffulli N. BASES position statement on guidelines for resistance exercise in young people. *J Sports Sci*. 2004;22:383-90.

22. Lloyd RS, Oliver JL, Faigenbaum AD, Myer GD, De Ste Croix MB. Chronological age vs. biological maturation: implications for exercise programming in youth. *J Strength Cond Res*. 2014;28(5):1454-64.
23. Balyi I, & Hamilton, A. Long-Term Athlete Development: Trainability in children and adolescents. Windows of opportunity. Optimal trainability. Victoria, BC.: National Coaching Institute British Columbia & Advanced Training and Performance Ltd.; 2004.
24. Ford P, De Ste Croix M, Lloyd R, Meyers R, Moosavi M, Oliver J, et al. The long-term athlete development model: physiological evidence and application. *J Sports Sci*. 2011;29(4):389-402.
25. Lloyd RS, Oliver JL. The youth physical development model: A new approach to long-term athletic development. *Strength and Conditioning Journal*. 2012;34(3):61-72.
26. The British Association of Sport and Exercise Sciences Expert Statements. *Journal of Sports Sciences*. 2014;32(sup2):s1-s3.
27. Weltman A, Janney C, Rians CB, Strand K, Berg B, Tippitt S, et al. The effects of hydraulic resistance strength training in pre-pubertal males. *Med Sci Sports Exerc*. 1986;18(6):629-38.
28. Fukunaga T, Funato K, Ikegawa S. The effects of resistance training on muscle area and strength in prepubescent age. *Ann Physiol Anthropol* 1992;11(3):357-64.
29. Shaibi GQ, Cruz ML, Ball GDC, Weigensberg MJ, Salem GJ, Crespo NC, et al. Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. *Med Sci Sports Exerc*. 2006;38(7):1208-2015.
30. Goldfield GS, Kenny GP, Alberga AS, Prud'homme D, Hadjiyannakis S, Gougeon R, et al. Effects of aerobic training, resistance training, or both on psychological health in adolescents with obesity: The HEARTY randomized controlled trial. *J Consult Clin Psychol*. 2015;83(6):1123-35.
31. Faigenbaum AD, Myer GD. Exercise deficit disorder in youth: play now or pay later. *Curr Sports Med Rep*. 2012;11(4):196-200.
32. Meinhardt U, Witassek F, Petro R, Fritz C, Eiholzer U. Strength training and physical activity in boys: a randomized trial. *Pediatrics*. 2013;132(6):1105-11.
33. Eiholzer U, Meinhardt U, Petro R, Witassek F, Gutzwiller F, Gasser T. High-intensity training increases spontaneous physical activity in children: a randomized controlled study. *J Pediatr*. 2010;156(2):242-6.

34. Biddle S, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. *British Journal of Sports Medicine*. 2011;45(11):886-95.
35. Must A, Anderson SE. Body mass index in children and adolescents: considerations for population-based applications. *Int J Obes*. 2006;30(4):590-4.
36. Cole TJ, Freeman JV, Preece MA. British 1990 growth reference centiles for weight, height, body mass index and head circumference fitted by maximum penalized likelihood. *Stat Med*. 1998;17(4):407-29.
37. Reilly JJ, Kelly J, Wilson DC. Accuracy of simple clinical and epidemiological definitions of childhood obesity: systematic review and evidence appraisal. *Obes Rev*. 2010;11(9):645-55.
38. Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med*. 2014;44(9):1209-23.
39. Yu CC, Sung RY, So RC, Lui KC, Lau W, Lam PK, et al. Effects of strength training on body composition and bone mineral content in children who are obese. *J Strength Cond Res*. 2005;19(3):667-72.
40. Alberga AS, Prud'homme D, Kenny GP, Goldfield GS, Hadjiyannakis S, Gougeon R, et al. Effects of aerobic and resistance training on abdominal fat, apolipoproteins and high-sensitivity C-reactive protein in adolescents with obesity: the HEARTY randomized clinical trial. *Int J Obes (Lond)*. 2015;39(10):1494-500.
41. Lubans DR, Aguiar EJ, Callister R. The effects of free weights and elastic tubing resistance training on physical self-perception in adolescents. *Psychol Sport Exerc*. 2010;11(6):497-504.
42. Lillegard WA, Brown EW, Wilson DJ, Henderson R, Lewis E. Efficacy of strength training in prepubescent to early postpubescent males and females: Effects of gender and maturity. *Pediatr Rehabil*. 1997;1(3):147-57.
43. Strong WB, Malina RM, Blimkie CJR, Daniels SR, Dishman RK, Gutin B, et al. Evidence Based Physical Activity for School-age Youth. *J Pediatr*. 2005;146(6):732-7.
44. Fairclough SJ, Boddy LM, Ridgers ND, Stratton G. Weight status associations with physical activity intensity and physical self-perceptions in 10- to 11-year-old children. *Pediatr Exerc Sci*. 2012;24(1):100-12.
45. Kreuser F, Kromeyer-Hauschild K, Gollhofer A, Korsten-Reck U, Rottger K. "Obese equals lazy?" analysis of the association between weight status and physical activity in children. *J Obes*. 2013;2013:437017.

46. Ferrari GL, Oliveira LC, Araujo TL, Matsudo V, Barreira TV, Tudor-Locke C, et al. Moderate-to-Vigorous Physical Activity and Sedentary Behavior: Independent Associations With Body Composition Variables in Brazilian Children. *Pediatr Exerc Sci*. 2015;27(3):380-9.
47. Alberga AS, Sigal RJ, Kenny GP. A review of resistance exercise training in obese adolescents. *Phys Sportsmed*. 2011;39(2):50-63.
48. Dietz P, Hoffmann S, Lachtermann E, Simon P. Influence of exclusive resistance training on body composition and cardiovascular risk factors in overweight or obese children: a systematic review. *Obes Facts*. 2012;5(4):546-60.
49. Schranz N, Tomkinson G, Olds T. What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A systematic review and meta-analysis. *Sports Med*. 2013;43:893-907.
50. Benson AC, Torode ME, Fiatarone Singh MA. Effects of resistance training on metabolic fitness in children and adolescents: a systematic review. *Obes Rev*. 2008;9(1):43-66.
51. Lee S, Kim Y, Kuk JL. What Is the Role of Resistance Exercise in Improving the Cardiometabolic Health of Adolescents with Obesity? *J Obes Metab Syndr*. 2019;28(2):76-91.
52. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents: review of associated health benefits. *Sports Med*. 2010;40(12):1019-35.
53. Behm DG, Young JD, Whitten JHD, Reid JC, Quigley PJ, Low J, et al. Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: a systematic review and meta-analysis. *Front Physiol*. 2017;8(423).
54. Brown T. Movement Assessment Battery for Children: 2nd Edition (MABC-2). In: Volkmar FR, editor. *Encyclopedia of Autism Spectrum Disorders*. New York, NY: Springer New York; 2013. p. 1925-39.
55. Bruininks RH BB. BOT-2, Bruininks-Oseretsky Test of Motor Proficiency Second Edition. Minneapolis, Minnesota: Pearson Assessments; 2005.
56. Ulrich D. Test of Gross Motor Development (2nd edition). Austin, TX.: Pro-Ed; 2000.
57. Ulrich D. Test of Gross Motor Development (3rd edition). Indianapolis: Pro-Ed; 2019.

58. Logan SW, Barnett LM, Goodway JD, Stodden DF. Comparison of performance on process- and product-oriented assessments of fundamental motor skills across childhood. *J Sports Sci.* 2017;35(7):634-41.
59. Holfelder B, Schott N. Relationship of fundamental movement skills and physical activity in children and adolescents: A systematic review. *Psychol Sport Exerc.* 2014;15(4):382-91.
60. Logan S, Kipling Webster, E, Getchell, N, Pfeiffer, K,A, Robinson, L,E. Relationship between fundamental motor skill competence and physical activity during childhood and adolescence: a systematic review. *Kines Rev.* 2015;4:416-26.
61. Lopes VP, Rodrigues LP, Maia JAR, Malina RM. Motor coordination as predictor of physical activity in childhood. *Scand J Med Sci Sports.* 2011;21(5):663-9.
62. Behringer M, Vom Heede A, Matthews M, Mester J. Effects of strength training on motor performance skills in children and adolescents: a meta-analysis. *Pediatr Exerc Sci.* 2011;23(2):186-206.
63. Harries S, Lubans D, Callister R. Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis. *J Sci Med Sport.* 2012;15:S222.
64. Lesinski M, Prieske O, Granacher U. Effects and dose-response relationships of resistance training on physical performance in youth athletes: A systematic review and meta-analysis. *Br J Sports Med.* 2016;13:781-95.
65. Malina RM. Motor development during infancy and early childhood: overview and suggested directions for research. *Int J Sport Health Sci.* 2004;2:50-66.
66. Ahn S, Fedewa AL. A meta-analysis of the relationship between children's physical activity and mental health. *J Pediatr Psychol.* 2011;36(4):385-97.
67. Liu M, Wu L, Ming Q. How does physical activity intervention improve self-esteem and self-concept in children and adolescents? Evidence from a meta-analysis. *PLOS ONE.* 2015;10(8):e0134804.
68. Fox KR, Corbin CB. The Physical Self-Perception Profile: Development and preliminary validation. *J Sport Exerc Psychol.* 1989;11:408-30.
69. Shavelson RJ, Hubner JJ, Stanton GC. Self-Concept: Validation of Construct Interpretations. *Rev Educ Res.* 1976;46(3):407-41.
70. Sabiston CM, Gilchrist JD, Brunet J. Self-Perception in Sport and Exercise. In: Horn TS, Smith AL, editors. *Advances in Sport and Exercise Psychology*. 4. Leeds, U.K.: Human Kinetics; 2019. p. 57-74.

71. Fox KR. Advances in the measurement of the physical self. In: Duda J, editor. *Advances in sport and exercise psychology measurement*. Morgantown. West Virginia.: Fitness Information Technology.; 1998. p. 295-310.
72. Harter S. *Manual for the Self-Perception Profile for Children*. Denver, CO: University of Denver; 1985.
73. Nigg CR, Courneya KS. Transtheoretical Model: examining adolescent exercise behavior. *J Adolesc Health*. 1998;22(3):214-24.
74. Eklund RC, Whitehead JR, Welk GJ. Validity of the Children and Youth Physical Self-Perception Profile: A Confirmatory Factor Analysis. *Res Q Exerc Sport*. 1997;68(3):249-56.
75. Ekeland E, Heian F, Hagen K, Coren E. Can exercise improve self esteem in children and young people? A systematic review of randomised controlled trials. *Br J Sports Med*. 2005;39(11):792-8.
76. Babic MJ, Morgan PJ, Plotnikoff RC, Lonsdale C, White RL, Lubans DR. Physical activity and physical self-concept in youth: systematic review and meta-analysis. *Sports Med*. 2014;44(11):1589-601.
77. Lubans DR, Cliff DP. Muscular fitness, body composition and physical self-perception in adolescents. *J Sci Med Sport*. 2011;14(3):216-21.
78. Allender S, Cowburn G, Foster C. Understanding participation in sport and physical activity among children and adults: a review of qualitative studies. *Health Educ Res*. 2006;21(6):826-35.
79. Dobbins M, De Corby K, Robeson P, Husson H, Tirilis D. School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6-18. *Cochrane Database Syst Rev*. 2009(1):CD007651.
80. Ten Hoor GA, Sleddens EFC, Kremers SPJ, Schols AMWJ, Kok G, Plasqui G. Aerobic and strength exercises for youngsters aged 12 to 15: what do parents think? *BMC Public Health*. 2015;15(1):994.
81. Ten Hoor GA, Plasqui G, Ruiter RA, Kremers SP, Rutten GM, Schols AM, et al. A new direction in psychology and health: Resistance exercise training for obese children and adolescents. *Psychology & Health*. 2016;31(1):1-8.
82. Pescud M, Pettigrew S, McGuigan MR, Newton RU. Factors influencing overweight children's commencement of and continuation in a resistance training program. *BMC Public Health*. 2010;10:709.

83. Collins H, Fawkner S, Booth JN, Duncan A. The effect of resistance training interventions on weight status in youth: a meta-analysis. *Sports Med - Open*. 2018;4(1):41.
84. Collins H, Booth JN, Duncan A, Fawkner S. The effect of resistance training interventions on fundamental movement skills in youth: a meta-analysis. *Sports Med - Open*. 2019;5(1):17.
85. Collins H, Booth JN, Duncan A, Fawkner S, Niven A. The effect of resistance training interventions on 'The Self' in youth: a systematic review and meta-analysis. *Sports Med - Open*. 2019;5(1):29.
86. Gopalakrishnan S, Ganeshkumar P. Systematic reviews and meta-analysis: Understanding the best evidence in primary healthcare. *J Family Med Prim Care*. 2013;2(1):9-14.
87. Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M, et al. Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ (Clinical research ed)*. 2008;337:a1655-a.
88. Chen T, Lin J, Lin Y, Xu L, Lu D, Li F, et al. Effects of aerobic exercise and resistance exercise on physical indexes and cardiovascular risk factors in obese and overweight school-age children: A systematic review and meta-analysis. *PLoS One*. 2021;16(9):e0257150.
89. Kelley GA, Kelley KS, Pate RR. Exercise and cardiovascular disease risk factors in children and adolescents with obesity: a systematic review with meta-analysis of randomized controlled trials. *American Journal of Lifestyle Medicine*. 2021:1559827620988839.
90. Guillem CM, Loaiza-Betancur AF, Rebullido TR, Faigenbaum AD, Chulvi-Medrano I. The effects of resistance training on blood pressure in preadolescents and adolescents: a systematic review and meta-analysis. *Int J Environ Res Public Health*. 2020;17(21):7900.
91. Yu WW, Lee S, Arslanian S, Tamim H, Kuk JL. Effects of exercise on resting metabolic rate in adolescents with overweight and obesity. *Childhood obesity (Print)*. 2021;17(4):249-56.
92. Magnani Branco BH, Carvalho IZ, Garcia de Oliveira H, Fanhani AP, Machado Dos Santos MC, Pestillo de Oliveira L, et al. Effects of 2 types of resistance training models on obese adolescents' body composition, cardiometabolic risk, and physical fitness. *J Strength Cond Res*. 2020;34(9):2672-82.
93. Chaabene H, Prieske O, Lesinski M, Sandau I, Granacher U. Short-term seasonal development of anthropometry, body composition, physical fitness, and

sport-specific performance in young olympic weightlifters. *Sports* (Basel, Switzerland). 2019;7(12):242.

94. Blagrove RC, Howe LP, Cushion EJ, Spence A, Howatson G, Pedlar CR, et al. Effects of Strength Training on Postpubertal Adolescent Distance Runners. *Med Sci Sports Exerc.* 2018;50(6):1224-32.

95. Alireza R, Abbas Ali G, Morad H, Jamshid M, Bahram M. Effects of Three Methods of Exercise Training on Cardiovascular Risk Factors in Obese Boys. *2017; سال بیست و هفتم: بیماریهای کودکان ایران.*

96. Lesinski M, Herz M, Schmelcher A, Granacher U. Effects of Resistance Training on Physical Fitness in Healthy Children and Adolescents: An Umbrella Review. *Sports Med.* 2020;50(11):1901-28.

97. Behm D, Young J, Whitten J, Reid J, Quigley P, Low J, et al. Effectiveness of Traditional Strength vs. Power Training on Muscle Strength, Power and Speed with Youth: A Systematic Review and Meta-Analysis. *Frontiers in Physiology.* 2017;8.

98. Raya-González J, Castillo D, de Keijzer KL, Beato M. The effect of a weekly flywheel resistance training session on elite U-16 soccer players' physical performance during the competitive season. A randomized controlled trial. *Research in sports medicine (Print).* 2021;29(6):571-85.

99. Negra Y, Chaabene H, Stöggl T, Hammami M, Chelly MS, Hachana Y. Effectiveness and time-course adaptation of resistance training vs. plyometric training in prepubertal soccer players. *Journal of Sport and Health Science.* 2020;9(6):620-7.

100. Pullen BJ, Oliver JL, Lloyd RS, Knight CJ. The Effects of Strength and Conditioning in Physical Education on Athletic Motor Skill Competencies and Psychological Attributes of Secondary School Children: A Pilot Study. *Sports.* 2020;8(10).

101. Ozmen T, Aydogmus M, Yana M, Simsek A. Effect of core strength training on balance, vertical jump height and throwing velocity in adolescent male handball players. *J Sports Med Phys Fitness.* 2020;60(5):693-9.

102. Fernandez Ortega JA, los Reyes YGD, Garavito Peña FR. Effects of strength training based on velocity versus traditional training on muscle mass, neuromuscular activation, and indicators of maximal power and strength in girls soccer players. *Apunts Sports Medicine.* 2020;55(206):53-61.

103. Liao T, Li L, Wang YT. Effects of Functional Strength Training Program on Movement Quality and Fitness Performance Among Girls Aged 12-13 Years. *J Strength Cond Res.* 2019;33(6):1534-41.

104. González-García J, Morencos E, Balsalobre-Fernández C, Cuéllar-Rayó Á, Romero-Moraleda B. Effects of 7-Week Hip Thrust Versus Back Squat Resistance Training on Performance in Adolescent Female Soccer Players. *Sports (Basel, Switzerland)*. 2019;7(4):80.
105. Winwood PW, Buckley JJ. Short-Term Effects of Resistance Training Modalities on Performance Measures in Male Adolescents. *J Strength Cond Res*. 2019;33(3):641-50.
106. Harries SK, Lubans DR, Buxton A, MacDougall THJ, Callister R. Effects of 12-Week Resistance Training on Sprint and Jump Performances in Competitive Adolescent Rugby Union Players. *J Strength Cond Res*. 2018;32(10):2762-9.
107. King JE, Jebeile H, Garnett SP, Baur LA, Paxton SJ, Gow ML. Physical activity based pediatric obesity treatment, depression, self-esteem and body image: A systematic review with meta-analysis. *Mental Health and Physical Activity*. 2020;19:100342.
108. Eldridge SM, Lancaster GA, Campbell MJ, Thabane L, Hopewell S, Coleman CL, et al. Defining Feasibility and Pilot Studies in Preparation for Randomised Controlled Trials: Development of a Conceptual Framework. *PloS one*. 2016;11(3):e0150205-e.
109. Arain M, Campbell MJ, Cooper CL, Lancaster GA. What is a pilot or feasibility study? A review of current practice and editorial policy. *BMC Medical Research Methodology*. 2010;10(1):67.
110. Cathain A, Croot L, Duncan E, Rousseau N, Sworn K, Turner KM, et al. Guidance on how to develop complex interventions to improve health and healthcare. *BMJ Open*. 2019;9(8):e029954.
111. Barnes M, Plisk S. NSCA strength & conditioning professional standards & guidelines. *Strength Cond J*. 2002;24(1):7-8.
112. Borga M, West J, Bell JD, Harvey NC, Romu T, Heymsfield SB, et al. Advanced body composition assessment: from body mass index to body composition profiling. *J Investig Med*. 2018;66(5):1.
113. Whitehead JR. A study of children's physical self-perceptions using an adapted physical self-perception profile questionnaire. *Pediatr Exerc Sci*. 1995;7(2):132-51.
114. Welk G, Eklund R. Validation of the children and youth physical self-perception profile for young children. *Psych Sport Exerc*. 2005:51-65.

115. Wind AE, Takken T, Helders PJ, Engelbert RH. Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? *Eur J Pediatr*. 2010;169(3):281-7.
116. Faigenbaum AD, Milliken LA, Westcott WL. Maximal strength testing in healthy children. *J Strength Cond Res*. 2003;17(1):162-6.
117. International Society of Anthropometry and Kinanthropometry. Manual. 2011.
118. Cicek B, Ozturk A, Unalan D, Bayat M, Mazicioglu MM, Kurtoglu S. Four-site skinfolds and body fat percentage references in 6-to-17-year old Turkish children and adolescents. *J Pak Med Assoc*. 2014;64(10):1154-61.
119. Flanagan SP, Laubach LL, de Marco Jr GM, Alvarez C, Borchers S, Dressman E, et al. Effects of two different strength training modes on motor performance in children. *Res Q Exerc Sport*. 2002;73(3):340.
120. Safrit MJ. Complete guide to youth fitness testing. 1995.
121. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-81.
122. Kim Y, Beets MW, Welk GJ. Everything you wanted to know about selecting the "right" Actigraph accelerometer cut-points for youth, but...: a systematic review. *J Sci Med Sport*. 2012;15(4):311-21.
123. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008;26(14):1557-65.
124. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*. 2011;43(7):1360-8.
125. Baechle TRE, R.W. Essentials of strength and conditioning. Third edition. ed. Champaign, IL: Human Kinetics; 2008.
126. French D, Jones, T., Kraemer, W.J. Strength development in youths. In: Lloyd RS, Oliver, J., editor. Strength and conditioning for young athletes: science and application. Oxon, UK.: Routledge; 2014.
127. Kraemer WJ, Fleck, S.J. Strength training for young athletes. Second edition ed. Champaign IL: Human Kinetics; 2005.
128. Faigenbaum AD, Westcott, W.L. Youth strength training. Second edition ed. Champaign IL: Human Kinetics; 2009.

129. Foster CE, Brennan G, Matthews A, McAdam C, Fitzsimons C, Mutrie N. Recruiting participants to walking intervention studies: a systematic review. *Int J Behav Nutr Phys Act*. 2011;8(1):137.
130. Francis D, Roberts I, Elbourne DR, Shakur H, Knight RC, Garcia J, et al. Marketing and clinical trials: a case study. *Trials*. 2007;8(1):37.
131. Longmuir PE, Boyer C, Lloyd M, Borghese MM, Knight E, Saunders TJ, et al. Canadian Agility and Movement Skill Assessment (CAMSA): Validity, objectivity, and reliability evidence for children 8–12 years of age. *J Sport Health Sci*. 2017;6(2):231-40.
132. Dishman RK, Motl RW, Saunders R, Felton G, Ward DS, Dowda M, et al. Enjoyment mediates effects of a school-based physical-activity intervention. *Med Sci Sports Exerc*. 2005;37(3):478-87.
133. Faigenbaum AD, Milliken LA, LaRosa Loud R, Burak BT, Doherty CL, Westcott WL. Comparison of 1 and 2 days per week of strength training in children. *Res Q Exerc Sport*. 2002;73(4):416-24.
134. Alberga AS, Farnesi BC, Lafleche A, Legault L, Komorowski J. The effects of resistance exercise training on body composition and strength in obese prepubertal children. *Phys Sportsmed*. 2013;41(3):103-9.
135. Lau PWC, Yu CW, Lee A, Sung RYT. The physiological and psychological effects of resistance training on Chinese obese adolescents. *J Exerc Sci Fit*. 2004;2(2):115-20.
136. Velez A, Golem DL, Arent SM. The impact of a 12-week resistance training program on strength, body composition, and self-concept of Hispanic adolescents. *J Strength Cond Res*. 2010;24(4):1065-73.
137. Benson AC, Torode ME, Fiatarone Singh MA. The effect of high-intensity progressive resistance training on adiposity in children: A randomized controlled trial. *International Journal of Obesity*. 2008;32(6):1016-27.
138. Mullane SL, Bocchicchio VB, Crespo NC. Feasibility and parental acceptability of an 8-week, slow-speed, high-intensity, community-based resistance training program for preadolescent children. *Fam Community Health*. 2017;40:183-91.
139. Zach S, Adiv T. Strength Training in Males and Females – Motives, Training Habits, Knowledge, and Stereotypic Perceptions. *Sex Roles*. 2016;74(7):323-34.
140. Logan SW, Ross SM, Chee K, Stodden DF, Robinson LE. Fundamental motor skills: A systematic review of terminology. *J Sports Sci*. 2018;36(7):781-96.

141. Raustorp A, Lindwall M. Physical self-esteem – a ten-year follow-up study from early adolescence to early adulthood. *Int J Adolesc Med Health*. 2015;27(1):31-9.
142. Moeskops S, Oliver JL, Read PJ, Cronin JB, Myer GD, Haff GG, et al. Within- and between-session reliability of the isometric midthigh pull in young female athletes. *J Strength Cond Res*. 2018;32(7):1892-901.
143. Davis JN, Tung A, Chak SS, Ventura EE, Byrd-Williams CE, Alexander KE, et al. Aerobic and strength training reduces adiposity in overweight latina adolescents. *Med Sci Sports Exerc*. 2009;41(7):1494-503.
144. McGuigan MR, Tatasciore M, Newton RU, Pettigrew S. Eight weeks of resistance training can significantly alter body composition in children who are overweight or obese. *J Strength Cond Res*. 2009;23(1):80-5.
145. Deci EL, Ryan RM. Self-determination theory. *Handbook of theories of social psychology*, Vol 1. Thousand Oaks, CA: Sage Publications Ltd; 2012. p. 416-36.
146. Edmunds J, Ntoumanis N, Duda JL. A test of Self-Determination Theory in the exercise domain. *J Appl Soc Psychol*. 2006;36(9):2240-65.
147. Collins HM, Fawkner S, Booth JN, Duncan A. The impact of resistance training on strength and correlates of physical activity in youth. *J Sports Sci*. 2021:1-10.
148. Faigenbaum A, Best TM, MacDonald J, Myer GD, Straccioli A. Top 10 research questions related to exercise deficit disorder (EDD) in youth. *Res Q Exerc Sport*. 2014;85(3):297-307.
149. Myers AM, Beam NW, Fakhoury JD. Resistance training for children and adolescents. *Transl Pediatr*. 2017;6(3):137-43.
150. Goodway JDS, R. Ruiz, A. The influence of project SKILL on the motor skill development of young disadvantaged Hispanic children. *Res Q Exerc Sport*. 2003;74(1):A12-A3.
151. Ramos Dos Santos C, Silva, C,C, Marques, I. Relationship between physical activity, physical fitness, and motor competence in school children. *Motricidade*. 2017;13:1-76.
152. Behringer M, Heede AV, Matthews M, Mester J. Effects of strength training on motor performance skills in children and adolescents: A meta-analysis. *Pediatr Exerc Sci*. 2011;23(2):186-206.

153. Keogh C, Collins DJ, Warrington G, Comyns T. Intra-Trial Reliability and Usefulness of Isometric Mid-Thigh Pull Testing on Portable Force Plates. *Journal of human kinetics*. 2020;71:33-45.
154. Yang CC, Hsu YL. A review of accelerometry-based wearable motion detectors for physical activity monitoring. *Sensors (Basel, Switzerland)*. 2010;10(8):7772-88.
155. Ward DS, Evenson KR, Vaughn A, Rodgers AB, Troiano RP. Accelerometer use in physical activity: best practices and research recommendations. *Med Sci Sports Exerc*. 2005;37(11 Suppl):S582-8.
156. Cooper AR, Goodman A, Page AS, Sherar LB, Esliger DW, van Sluijs EMF, et al. Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD). *Int J Behav Nutr Phys Act*. 2015;12(1):113.
157. Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175-91.
158. Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates.; 1988.
159. Thivel D, Isacco L, O'Malley G, Duché P. Pediatric obesity and perceived exertion: difference between weight-bearing and non-weight-bearing exercises performed at different intensities. *J Sports Sci*. 2016;34(5):389-94.
160. Schranz N, Tomkinson G, Olds T. What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A Systematic review and meta-analysis. *Sports Med*. 2013;43(9):893-907.
161. Granacher U, Goesele A, Roggo K, Wischer T, Fischer S, Zuerny C, et al. Effects and mechanisms of strength training in children. *Int J Sports Med*. 2011;32(5):357-64.
162. Ozmun JC, Mikesky AE, Surburg PR. Neuromuscular adaptations following prepubescent strength training. *Med Sci Sports Exerc*. 1994;26(4):510-4.
163. Stodden DF, Goodway JD, Langendorfer SJ, Robertson MA, Rudisill ME, Garcia C, et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest*. 2008;60(2):290-306.
164. Estevan I, Barnett LM. Considerations related to the definition, measurement and analysis of perceived motor competence. *Sports Med*. 2018;48(12):2685-94.

165. Harrison F, Goodman A, van Sluijs EMF, Andersen LB, Cardon G, Davey R, et al. Weather and children's physical activity; how and why do relationships vary between countries? *International Journal of Behavioral Nutrition and Physical Activity*. 2017;14(1):74.
166. Trudeau F, Shephard RJ. Contribution of School Programmes to Physical Activity Levels and Attitudes in Children and Adults. *Sports Medicine*. 2005;35(2):89-105.
167. Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport*. 2000;71(2 Suppl):S59-73.
168. Jeffery AN, Voss LD, Metcalf BS, Alba S, Wilkin TJ. Parents' awareness of overweight in themselves and their children: cross sectional study within a cohort (EarlyBird 21). *BMJ (Clinical research ed)*. 2005;330(7481):23-4.
169. Faigenbaum A, Zaichkowsky LD. Psychological effects of strength training on children. *J Sport Behav*. 1997;20(2):164.
170. Robertson W, Stewart-Brown S, Wilcock E, Oldfield M, Thorogood M. Utility of accelerometers to measure physical activity in children attending an obesity treatment intervention. *J Obes*. 2011;2011.
171. McCann DA, Knowles ZR, Fairclough SJ, Graves LEF. A protocol to encourage accelerometer wear in children and young people. *Qual Res Sport Exerc Health*. 2016;8(4):319-31.
172. Robinson LE, Stodden DF, Barnett LM, Lopes VP, Logan SW, Rodrigues LP, et al. Motor competence and its effect on positive developmental trajectories of health. *Sports Med*. 2015;45(9):1273-84.
173. FBASES GS, Foweather L, Collins H, Stodden D. The BASES Expert Statement on the Importance of Fundamental Movement Skills for Children's Physical Activity and Health. [h/p/cosmos Gaitway 3D](http://cosmos.gaitway3d.com).6.
174. Teixeira PJ, Carraça EV, Markland D, Silva MN, Ryan RM. Exercise, physical activity, and self-determination theory: A systematic review. *Int J Behav Nutr Phys Act*. 2012;9(1):78.
175. Deci EL, Ryan RM. The "what" and "why" of goal pursuits: human needs and the Self-Determination of Behavior. *Psychol Inq*. 2000;11(4):227-68.
176. Vierling KK, Standage M, Treasure DC. Predicting attitudes and physical activity in an "at-risk" minority youth sample: A test of self-determination theory. *Psychol Sport Exerc*. 2007;8(5):795-817.

177. Higgins JPT TJ, Chandler J, Cumpston M, Li T, Page MJ, Welch VA. Cochrane Handbook for Systematic Reviews of Interventions version 6.2. Available from www.training.cochrane.org/handbook. 2021.
178. Rowlands AV. Accelerometer assessment of physical activity in children: an update. *Pediatr Exerc Sci*. 2007;19(3):252-66.
179. Reilly JJ, Penpraze V, Hislop J, Davies G, Grant S, Paton JY. Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child*. 2008;93(7):614-9.
180. Westerterp KR. Assessment of physical activity: a critical appraisal. *Eur J Appl Physiol*. 2009;105(6):823-8.

APPENDICES

Appendix 1



Institute of Sport
and Exercise
University of Dundee

Across Europe, less than 50% of young people are doing enough physical activity and there is a decline in physical activity levels with age with; 25% of 11 years olds meet the recommendations, compared to just 16% of 15 year olds.

The current physical activity guidelines for children include ‘activity to strengthen muscle and bone’ and it has been suggested that those who do not enhance their muscular strength and movement skills early in life may not develop in a way that would allow them to participate in a variety of activities and sports with confidence later in life.

There are many benefits of strength-based sessions for children, including improving confidence, developing motor skills and preventing of obesity. This type of exercise session is safe and appropriate for all children, if it is designed and delivered by qualified staff.

Proposal ideas

Who?

- Age group – P5/P6. Across the year group – 12 pupils maximum.
- Coach information – There will always be a UKSCA (United Kingdom Strength and Conditioning Association) Accredited Coach, who is PVG checked at each of the sessions. There will be 2 coaches at each session.

What?

- University ethics approval has been attained.
- Recommend the delivery of some taster sessions at the school to gain interest and for pupils/parents to see how the sessions will run and what the content will be like.
- 5 week after school programme (commencing wk/bg **22nd October**, initial assessment in week 1 followed by 4 weeks of training).
- 2 weeks at school, 2 weeks at the Institute of Sport & Exercise, University of Dundee. 2 sessions per week. 45 minutes per session.
- Assessment information – the participants would be asked to complete the following assessments:
 - Questionnaire to look at self-confidence (the Physical Self Perceptions Profile).
 - A functional movement assessment (how good are their movement/motor skills?)
 - Weight status (height, weight, skinfolds (tricep, under the shoulder blade and calf), arm girth, waist and hips.)
 - Strength assessment – maximal testing on machine weights.
 - Physical Activity – accelerometer to be worn for 1 week – exercise diary to assess the intensity of exercise.
- Programme content – movement development based warm up, strength section, cool down.

- Following the 5 weeks, there will be a feedback session with pupils and parents to evaluate the programme and hope to develop a longer pilot study in January and the pupils can take part in this second study if they'd like to continue the sessions.

Appendix 2

Active Strength: Taster Session

Warm up

- Make sure we are warmed up so our bodies are ready for exercises and so we don't hurt ourselves - Bean game – runner bean (run on the spot), spring bean (jump on the spot), baked bean (lay on the floor in the sun)
- Animal walks – SLOW AND SILENT! Lots of different ones – what ones do you know? We will do: bear crawl, crab, monkey gallop sideways – in 5 lines – get to cone 1, if you feel you can go further, go to cone 2 and then walk back around the edge.
 - Why do we do them? Strength and flexibility to control your body – you need to go slow to get stronger.

Main section

- **Body weight exercises (technique and basics)** – We can get stronger by using our body weight. Because we want to get strong movements, not strong muscles, we are going to do squats, lunges and push ups. 2 lines facing your partner.
 - **Squats** – toes turned out, back nice and straight, arms out in front, chest up, bum back and down towards the floor but keep your chest up – what if you put your hands behind your head? Why is a squatting movement useful – jump, stronger legs and core, run faster, uses your whole body.
 - **Push ups – get in pairs – face each other** - start on knees – keep your back straight, hands where comfortable but approx. just wider than shoulders, look between hands (head/neck in line with back), lower chest to the floor – slow and controlled. Once you have done a couple of good ones do them at the same time as your partner and see if once you have pushed up if you can shake hands with your partner? Can you do it with the other arm? Why are push ups useful? Not just chest and arms, uses core as well.
- **Broomstick exercises**
 - In a line – frog jumps with broomstick overhead.
 - In pairs – take it in turns, split jerk (fun, lunge position), full body power, big shout when do the jerk
- **Arm wrestle** – in pairs, lie on the floor – who was the winner? Does this make you the strongest? Importance of strong movements not muscles!

Appendix 3



Institute of Sport
and Exercise
University of Dundee

Active Strength

“Active strength is a project to help children become stronger, healthy and active”

What is it?

Physical activity is crucial for health and by helping your child to develop strength, motor skills and confidence, we promote an active and healthy lifestyle through a fun and engaging strength based programme.

Who are we?

We are Strength Coaches at the University of Dundee (accredited through the UK Strength and Conditioning Association) who are PVG checked and have many years of experience in coaching children to become stronger.

What will my child do?

1 assessment, 2 sessions at the University and 2 sessions at the school. There will be a longer project in the New Year, this is to see how the programme will work.

- *Assessment* - strength, confidence, movement skills, body composition and physical activity levels.
- *Programme* - strength based sessions will involve a combination of body weight and movement based exercises – we are training stronger movement, not muscles!

What's the benefit?

Strength based exercises have been shown to improve strength, movement skills, confidence and maintain a healthy body weight in children.

For more information

Contact Helen Collins - [01382 385674](tel:01382385674) or h.collins@dundee.ac.uk

Appendix 4



Active Strength Project

Dear Parent/Guardian/Carer

My name is Helen Collins and I am a Sport & Exercise Scientist at the University of Dundee and also a PhD student at the University of Edinburgh, and I am asking if your child would like to have an opportunity to take part in an exciting training opportunity through the School.

Background to the project

I am investigating the effect of resistance training on physical activity levels in youth. It has been shown that resistance exercise in children can have a positive effect on confidence, developing motor skills and obesity prevention, but the role it plays in helping to increase physical activity is not known. We are therefore conducting research to try and explore this in more detail.

As an after school initiative called 'Active Strength', I will be hoping to recruit 10 children from the Primary 5 year group to take part in a short feasibility study, and I would like to invite your child to take part.

What will my child be asked to do?

The programme will involve your child undertaking some assessments (strength, confidence, physical activity, movement skills, body size), two separate weeks of the 'Active Strength' training programme (movement skills and body weight exercises), and a follow up focus group to evaluate the programme.

Dates?

The dates we have currently decided on for the 4 sessions and the focus group are:

Monday 20th and Thursday 23rd November – from 3.30-4.30pm at the Institute of Sport and Exercise, University of Dundee

Monday 4th and Thursday 7th December – from 3.30-4.30pm at Blackness Primary

Focus group - Monday 11th OR Thursday 14th December – from 3.30-4.30pm at Blackness Primary.

I also need to schedule an assessment session (details attached) at the University which will last approximately 1.5 hours but would like to know when would work best to do this (it doesn't need to be before these sessions start but needs to be before Christmas).

If you would like your child to take part, please can you respond by **Wed 15th November**. Additionally, if you know of any other parents of PS children who may be interested in their child being involved, then could you pass on my details?

Many thanks!

For further information about this study:

Helen Collins

Tel 01382 385674

Appendix 5



THE UNIVERSITY
of EDINBURGH



Parent/Guardian/Carer Information Sheet Active Strength Project

Dear Parent/Guardian/Carer

My name is Helen Collins and I am a Sport & Exercise Scientist at the University of Dundee and also a PhD student at the University of Edinburgh, and I am asking if your child would like to have an opportunity to take part in an exciting training opportunity through the School.

Background to the project

I am investigating the effect of resistance training on physical activity levels in youth. Across Europe, less than 50% of young people are doing enough physical activity and there is a decline in physical activity levels with age. Only 25% of 11 years olds meet the recommendations, compared to just 16% of 15 year olds. To help combat this, it has been shown that resistance exercise in children can have a positive effect on confidence, developing motor skills and obesity prevention, but the role it plays in helping to increase children's physical activity is not known. We are therefore conducting research to try and explore this in more detail.

As an after school initiative called 'Active Strength', I will be hoping to recruit 10 children from the Primary 5 year group to take part in a short feasibility study, and I would like to invite your child to take part.

What will my child be asked to do?

The programme will involve your child undertaking some assessments, 2 separate weeks of the 'Active Strength' training programme, and a follow up focus group to evaluate the programme.

1) Assessments

There will be several assessments undertaken at the Institute of Sport and Exercise at the University of Dundee (ISE, dates to be confirmed). These will include the following:-

- a questionnaire to assess how you child feels about doing physical activity and about their physical abilities, which will be a short 5 minute paper and pen questionnaire
- a fundamental movement screen which include various run, jump and balance tests which your child will be asked to do to the best of their ability. This assessment will be videoed so that we can look at your child's movement patterns in more detail following the assessment
- A strength assessment on the weights machines in the gym (the leg press and the chest press).
- height and weight
- body size measurements which involve a standard measure of body composition and involves measuring the thickness of the fat tissue at the back of the arm, under the shoulder blade and the calf using callipers, and the circumference of the arm, waist and hips using a tape measure. Children will be asked to wear a t-shirt and shorts for this measurement, and there will always be two adults present during measurement, at least one of the same sex.

The University Non-Clinical Research Ethics Committee of the University of Edinburgh



THE UNIVERSITY
of EDINBURGH



University
of Dundee

- Your child will be given an accelerometer, which is a small device like a pedometer, to be worn on a belt around their waist during waking hours for 7 days. Alongside this, they will be asked to complete a simple diary of their physical activity for this week. This will be collected during the first exercise session.

2) The 'Active Strength' training programme

This will run for 2 separate weeks, twice a week. For the first week, the sessions will be at the Institute of Sport and Exercise (ise), the University of Dundee and for the second week, the sessions will be at the school. It is possible for myself and the second coach to walk with the children from the school to ISE (approximately 10 minutes) and will walk back to the school with them following the session if required. The Head Teacher is aware of this and you can opt in or out of this option (see below).

The sessions will be on Mondays and Thursdays from 3.30-4.30pm (we will return to the school at approximately 4.45pm). Each session will involve a warm up, a resistance based section and then a cool down. The exercises will be appropriate for the age and ability of your child, and will be fun and engaging sessions. Your child should wear what they usually would wear for PE (eg. shorts, t-shirt and trainers) and they should bring along a bottle of water with a name label on if possible.

3) Follow up

Following the study, you and your child will be invited to be part of a focus group so we can discuss and evaluate the programme. There will be two opportunities to attend the focus group sessions which will be the Monday and Thursday of the week following the study at the school from 3.30-4.30pm. This will then inform a follow up study and your child will be offered the opportunity to be part of this if they would like to.

Who will be involved?

I am a UKSCA (United Kingdom Strength and Conditioning Association) Accredited Coach and will be in attendance at all sessions. There will also be a second qualified coach at each session. All coaches are PVG members and have years of experience working with children.

Participation and termination

You will be able to withdraw your child's data from being used for research purposes, without explanation and without any negative consequences.

Risks

There is a small risk of pain or discomfort during the session. If your child feels any pain or discomfort, they will be advised to stop immediately and inform myself. During the study, if there are any concerns identified regarding your child's welfare identified by the Coaches then school procedures regarding this will be followed.

The University Non-Clinical Research Ethics Committee of the University of Edinburgh



THE UNIVERSITY
of EDINBURGH



University
of Dundee

How will the data be used?

Data collected will be anonymised and kept on a secure PC at the University of Dundee and paper forms will be kept in a locked cabinet within the Institute of Sport & Exercise, University of Dundee. The data collected will only be available to myself and my PhD supervisors (Samantha Fawcner, Josie Booth and Audrey Duncan) and the data will be stored for no more than 5 years. A summary of my findings will be made available to staff, pupils and parents/guardians.

Photos

For the purpose of publicising this project we would like to take some photos to be used for social media and for research presentations/publications. Please circle whether you would like to opt in or opt out.

OPT IN OPT OUT

Walk to and from school

Please circle whether you would like to opt in or opt out for us to walk your child from the school to the University of Dundee and then back to the school following the sessions.

OPT IN OPT OUT

For further information about this study:

Helen Collins will be glad to answer your questions about this study at any time. You can contact Helen at;

Institute of Sport & Exercise
University of Dundee
DUNDEE
DD1 4HN
Tel 01382 385674



THE UNIVERSITY
of EDINBURGH



University
of Dundee

Informed Consent Form Active Strength Project

Title of the Study:

The effect of a resistance training intervention on physical activity levels in youth: a feasibility study.

Consent

By signing below, you are agreeing that you have read and understood the Information Sheet, that you have had a chance to ask any questions about the study, and that you agree that your child's participation and that their data may be used for research purposes. Your child will not be individually identifiable if their data is presented as part of a research paper or conference presentation.

Parent/Guardian's name - printed

Parent/Guardian's Signature

Date

Researcher's name - printed

Researcher's Signature

Date

The University Non-Clinical Research Ethics Committee of the University of Edinburgh

Appendix 6



Children's PAR-Q Screening Form

Childs name:
Address:

Parent/Guardian/Carer name:

Childs Date of Birth:
Emergency Contact Details:
GP Surgery and Telephone Number:

Current Age:

Health Questions:

Does your child have or has he or she ever experienced any of the following?

1. Please Circle High or Low Blood Pressure Y / N
2. Elevated blood cholesterol Y / N Diabetes Y / N
3. Chest pains brought on by physical exertion Y / N
4. Childhood epilepsy Y / N
5. Dizziness or fainting Y / N
6. Any bone, joint or muscular problems with arthritis Y / N
7. A pathological condition or disability which affects movement, (eg cerebral palsy/dyspraxia) Y/N
8. Asthma or respiratory Problems Y / N
9. Any sustained injuries or illness Y / N
10. Any allergies Y / N
11. Is your child taking any medication Y / N
12. Has your doctor ever advised your child to exercise Y / N
13. Is there any reason not mentioned above why any type or physical activity may not be suitable for your child Y / N
14. Any behavioural or neuropsychological disorder such as ADHD Y / N

If you have answered 'YES' to any of the above questions please give full details here, and speak to the Researcher regarding exclusion from the project or medical clearance.

Appendix 6



THE UNIVERSITY
of EDINBURGH



University
of Dundee

In signing this form, I the parent/guardian/carer of the aforementioned child, affirm that I have read this form in its entirety and I have answered the questions accurately and to the best of my knowledge. I understand that my child is responsible for monitoring him or herself throughout any activity, and should any unusual symptoms occur, my child understands the importance of informing the Coach immediately.

In the event that medical clearance must be obtained before my child's participation in an exercise session, I agree to contact the GP and obtain written permission prior to the commencement of the exercise activity, and that the permission be given to the Researcher. I understand that if my child fails to behave in a manner that is polite and social, he or she could be suspended from that particular activity.

Parent/guardian/carers's signature: _____

Please print name: _____

Date: _____ Email: _____

Appendix 7



Physical Activity

Name:

Accelerometer code:

Instructions

The wGT3X-BT is a body worn device that measures and records physical movement associated with daily activity.

Fasten the belt snugly around the waist and position the accelerometer in line with the armpit and knee with the USB port cover facing up.

This should be worn during waking hours for 7 days.

For contact sports and water based activities, remove the accelerometer (it can't get wet!) but note the activity below. I will need the type of activity, the duration and intensity (light - equivalent of a stroll, moderate - equivalent of a brisk walk, light jog, vigorous - quite breathless, most sporting activities, or a combination of intensity).

Appendix 8

Part a – focus group questions

Children	Parents
1. Did you prefer the session at school or in the Strength Development Centre at the University? Why? 2. What did you like in particular about the session/s? 3. Do you like how the Strength Development Centre looks? 4. Did you find the assessments ok? Did you feel uncomfortable at all?	1. Is it easier for you for the after-school sessions to be at the school or at the University? 2. Is it easier for you to have the sessions straight after school or later on? What time would work best? 3. Would your child be able to commit to 2 sessions a week? 4. Do you have any other comments/suggestions regarding logistics that may encourage other parents to include their children in the project?

Part a – Focus group responses

From the focus group, the children identified that:

- They preferred the university session to being at school due to equipment, less chaotic, more exercises being completed in the session and simply that they were not at school.
- They enjoyed pull ups, the 1RM testing and the plank challenge (knocking your partner over).
- They found some of the instructions for the FMS assessment unclear.
- They would like two strength sessions per week but no more as they might get bored.
- They like the 'Strength Development Centre' environment and that the colours were child friendly and bright.
- They found that the CY-PSPP took quite a long time to do and one child found it difficult to understand.
- They found the accelerometer was annoying, it fell down, there was too much strapping and it dug in.

The parents identified that:

- The CY-PSPP questionnaire was interesting but it took more than one session to go through it. One parent identified that the 'body attractiveness' questions were inappropriate for the child's age.
- The sessions at the university would be best either straight after school or after 6pm.
- Twice a week might be too much with a lot of other activities.

Part a - Online questionnaire responses

1. My child did not attend the project due to:

- The most frequent response (27.8%, n=5) identified being busy at the allocated times.
- It was too close to Christmas (16.7% , n=3).
- Too many other activities (16.7%, n = 3).
- Not being interested (5.6%, n = 1).
- No one to take her to the University (5.6%, n = 1).
- On holiday (5.6%, n = 1).
- Unwell (5.6% n = 1).

2. What can we do to assist you in having your child involved in the project?

- The largest response was 33.3% (n = 7) that identified having more days available for the sessions.
- The next largest response was 23.8% (n = 5) of the responses that identified having someone collect the children from the school and walk them back afterwards.
- Have the sessions later in the evening (9.5% n=2).
- Have separate sessions for boys and girls (4.8% n = 1).
- Please give plenty of warning for dates (4.8% n = 1).
- Do it in school time (4.8% n = 1).

Appendix 9



Institute of Sport
and Exercise
University of Dundee

Active Strength

★ fun ★ healthy ★ active ★ safe

Is your child not particularly interested in playing sport, could benefit from increasing their physical activity levels (they maybe don't do a lot of after school activity) and is looking for something different and fun?

Then this fantastic opportunity is not to be missed!

What is it?

The Active Strength research project involves a fun, safe and engaging strength programme that will help your child to develop: strength, motor skills, confidence, to maintain a healthy body weight and ultimately become healthier and more active.

Who are we?

We are Strength Coaches at the University of Dundee (accredited though the UK Strength and Conditioning Association) who are PVG checked and have many years of experience working with children.

What will my child do?

An assessment at the start and end of the project. Two sessions per week at the University for 4 weeks.

- *Assessment* - strength, confidence, movement skills, body composition and physical activity levels.
- *Programme* - strength based sessions will involve a combination of body weight and movement based exercises – we are training stronger movement, not muscles!

For more information: Helen Collins - 01382 385674 or

h.collins@dundee.ac.uk

Appendix 10

Dear Sir/Madam

My name is Helen Collins and I work at the University of Dundee and am doing a PhD on resistance training in children and the impact it may have on physical activity levels. I am conducting a pilot study due to start on January 15th and am looking to recruit some 8-10 year old children to come along to the University for some free sessions after school. In particular, I'd like to get those involved who would benefit from being more physically active.

I have enclosed some posters if it would be possible to put them up in the school and also, if it would be possible to email parents with the following information detailed below, that would be very helpful.

I would very much appreciate your help.

Yours Sincerely

Helen Collins

Dear Parent/Guardian/Carer

My name is Helen Collins and I work at the University of Dundee and am doing a PhD in collaboration with Edinburgh University on physical activity in children. The 'Active Strength' research project is looking at the effect of resistance training on physical activity levels. In particular, I am looking to recruit children from 8-10 years old who would benefit from being more active. I am conducting a pilot study to start on the 15th of January for some free sessions at the University as an after school club and I invite your child to take part.

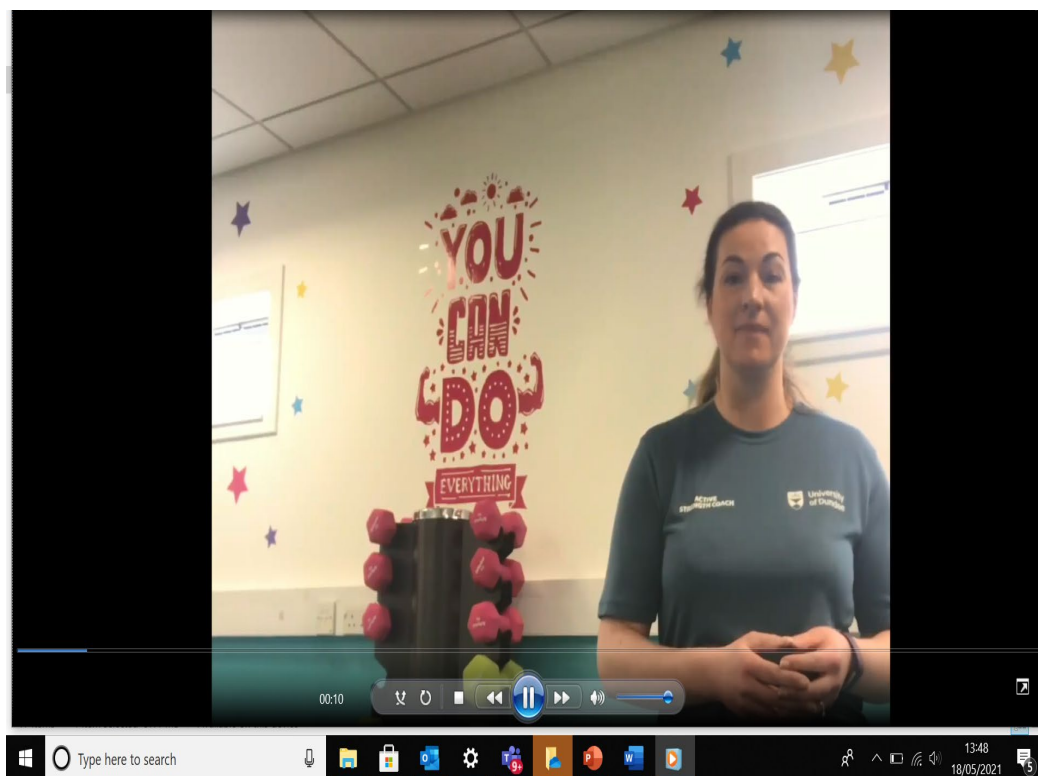
If you are interested in your child being involved and would like more information, please email me at h.m.collins@dundee.ac.uk or call me on: 01382 385674.

Many thanks!

Helen

Appendix 11

<https://www.youtube.com/watch?v=qNmIF1ph9BA&t=18s>



19/05/2021



1

Introductions

Helen Collins
Sport and Exercise Scientist
h.m.collins@dundee.ac.uk

- 15+ years experience of working as a Sport and exercise scientist - exercise physiology & S&C
- 15+ years of developing and teaching Sports Biomedicine at UoD
- UKSCA Accredited Strength and Conditioning Coach.
- Twice silver medalist at the World Masters Weightlifting Championships.
- Current PhD student at the University of Edinburgh - topic: Resistance training and physical activity in children.



www.dundee.ac.uk

2

Coaches

Paul McPate:

- UKSCA Accredited Coach
- Range of Involvement In working with youth strength training.
- Coaching experience - athletes across a wide range of sports and at all levels of the development continuum, from complete beginner to senior International level.

Cameron Soutar:

- BSc In Strength and Conditioning.
- Youth tennis players, badminton players, football players and swimmers.

Greg Whyte:

- PT Level 3.
- Coaching and management of youth performance programmes, with particular experience in swimming and football.

www.dundee.ac.uk

3

The Background

- There are current guidelines for how much physical activity children should do to maintain a basic level of health.

These are:

- At least 60 minutes of physical activity every day - this should range from moderate activity, such as walking and playground activities, to vigorous activity, such as running and tennis.
- On three days a week, these activities should involve exercises for strong muscles, such as push-ups, and exercises for strong bones, such as jumping and running.
- Children and young people should reduce the time they spend sitting watching TV and playing computer games.



www.dundee.ac.uk

4

The Background

- Physical activity levels in children is a problem.
- In Scotland, 27% of children are not meeting the PA guidelines and studies show that PA decreases with age.
- Originally adolescence was seen as a problematic age with regards to a decline in PA but now it has been shown to be much younger.
- Longitudinal study tracking children from 7-15 years found a gradual decline in PA
- PA in Scotland has been found to decline from the age of 6.



www.dundee.ac.uk

5

Why is physical activity so important?

Physical inactivity is associated with many risks. For example:

- Obesity
- Type 2 diabetes
- Heart disease
- Certain cancers
- Depression

Physical inactivity is the 4th leading cause of death worldwide, which is higher than obesity (high blood pressure, tobacco use and high blood glucose are the top 3)



www.dundee.ac.uk

6

19/05/2021

Why is physical activity so important?

- Appropriate practice of physical activity assists young people to:
- develop healthy musculoskeletal tissues (i.e. bones, muscles and joints)
 - develop a healthy cardiovascular system (i.e. heart and lungs)
 - develop neuromuscular awareness (i.e. coordination and movement control)
 - maintain a healthy body weight.
 - Improve their control over symptoms of anxiety and depression.
 - develop socially by providing opportunities for self-expression, building self-confidence, social interaction and integration.
 - It has also been suggested that physically active young people demonstrate higher academic performance at school.

7

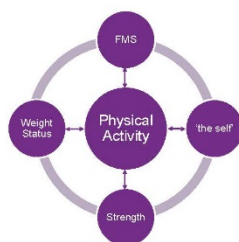
Important linking factors

- 60 minutes of MVPA per day.
- Are children physically capable of meeting the guidelines?

- Do they have the movement skills?
- Do they have the confidence?
- Are they hindered by body weight?
- Do they have the strength?

'activities to strength muscle and bone?...'

8



9

The possible answer?

Strength-based exercise!... Or resistance training.

BASES - "Resistance training is exercise specifically designed to enhance muscular strength."

... It may involve a variety of activities such as weight and load bearing exercises (eg climbing), specific body weight exercises (eg press ups) and the use of resistance materials (eg weights).



10

Perceptions?

- Stunt growth
- Cause injury
- Children shouldn't have big muscles.
- It should only be for sporty kids.
- What else?



11

Perceptions?

Strength based exercise....

Helen Collins
@helen_collins

Celebrity PTs are not experts in this area. Very frustrating message. Appropriate strength training is hugely beneficial from a young age.

The Times of London @thetimes
Should you let your child lift weights at the gym? (https://www.thetimes.co.uk/article/should-you-let-your-child-lift-weights-at-the-gym-3h8m8x5c7g8g2)



12

19/05/2021

Strength Exercise in Youth

- There has been lots of research done on the benefits of **appropriate resistance exercise** in youth.

- These include:

- Reduced chance of injury.
- Stronger muscles and bones.
- Better movement skills (run, jump, throw...)
- Increased confidence.
- Maintain a healthy weight status.

***It's not just
about sport...
it's important
for health!***

13

My Research Question

*Can a resistance training intervention
have a positive effect on physical
activity levels in youth?*

14

Active Strength

- **Pilot Study**

- 23rd April – assessment week.
 - Strength, FMS, 'self', weight status, physical activity levels.
 - Intervention group or control group.
- *Intervention group* – Programme: 30th April – 25th May
- 28th May - Re-assessment week
- *Control group* – Programme: 4th June – 29th June
- Two sessions per week.
- Choice of Monday, Tuesday or Thursday (must commit to the same two days each week)
- 4-4.45pm in the Strength Academy, ISE.

15

Any questions?

Helen Collins

E-mail: h.m.collins@dundee.ac.uk

16

Part b - Focus group questions and responses

Children

1. What did you like about the sessions?
 - Being able to beat my score each session.
 - The hanging challenge.
 - Everything.
 - Deadlifts.

2. What do you dislike about the sessions?
 - Nothing.
 - Deadlifts are too difficult, I was scared I'd hurt myself.
 - Can't be loud due to offices.

3. Do you like how the Strength Development Centre looks? How would you change it?
 - Too small.
 - Looks nice.

4. Did you find the assessments ok?
 - Fine
 - Describing yourself was hard.

5. How did you find wearing the accelerometer?
 - Forgot to wear accelerometer, straps annoying.
 - A diagram of where it should go would be useful.
 - Kids at school kept asking/pulling at the straps.

6. How do you think we could get other children to come along?
 - Have it at Dawson's park.
 - Advertising in schools.

7. Would you want to take part again?
 - Yes x 4, 2 x no

Parents

1. Were the times ok, did you find it easy to get and here and parked?
 - Straight after school is good.
 - 45 minutes enough time to go and do something.
 - A bit of a rush for some to get here.
 - Not much nearby for parents.
 - 45 minutes not much time to go and do something.

2. How did you find being able to commit to 2 sessions a week?
 - 2 sessions ok for some, not for others (50/50 split).

3. How do you think the sessions went and do you have any concerns or questions?
 - Positive feedback from the children.
 - No concerns.
 - Heavy bar for assessments on shoulders.

4. Do you have any other comments/suggestions regarding logistics that may encourage other parents to include their children in the project?
 - Changing facilities would be helpful.
 - An opportunity to see what goes on.
 - Whatsapp group very useful.
 - Nice to see photos on Facebook.
 - Free membership.
 - At a school would be better as a familiar place.