The efficacy of school-based interventions to increase MVPA and MBSE outcomes in adolescent males. A Systematic Review and Meta-Analysis

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AC, SJF, MCK, and RJN are aware of, and agree to this preprint submission.

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Abstract

Background: It has been reported that boys' and girls' physical activity (PA) levels decline throughout adolescence. Boys are at risk of physical inactivity during adolescence however, in intervention research they are an under-represented group relative to girls. It is suggested that the school environment may be central to developing interventions that support adolescents in meeting the current PA guidelines. The purpose of this systematic review and meta-analysis was to investigate the efficacy of school-based interventions to increase moderate to vigorous physical activity (MVPA) and muscle and bone strengthening exercise (MBSE) outcomes in adolescent males.

Methods: This systematic review and meta-analysis followed the preferred reporting systems for meta-analyses guidelines and was registered on PROSPERO (Registration number: CRD42018091023). Eligible studies were published in English within peer-reviewed articles. Searches were conducted in three databases, with an additional grey literature search in Google Scholar. Studies with MVPA and MBSE as outcomes were included.

Results: There were 51 data sets identified across 15 studies, from eight countries. Overall methodological quality of the studies was moderate to strong. Significant, small effect sizes were identified following a pooled analysis of all studies which aimed to increase MVPA and MBSE outcomes ($g = 0.26$, 95% CI = 0.15, 0.37, $P = <.001$). Interventions targeting MVPA were ineffective ($g = -0.09$, 95% CI -0.72, -0.53, $P = 0.77$). Interventions targeting MBSE evidenced a small to medium effect ($g = 0.27$, CI 0.16, 0.39, $P = <.001$). Sub-group analyses of MBSE delivery method resulted in small to medium effects: Upper limb MBSE ($g = 0.23$, 95% CI 0.03, 0.43, $p = 0.02$), lower limb MBSE ($g = 0.21$, 95% CI 0.09, 0.33, $p <0.00$), combined resistance activities ($g = 0.22$, 95% CI 0.05 – 0.39, $p <0.00$), plyometric activities ($g = 0.39$, 95% CI 0.09, 0.68, $p = 0.01$), body weight ($g = 0.21$, 95% CI -0.00, 0.44, $p = 0.05$), and traditional MBSE methods ($g = 0.43$, 95% CI -0.09, 0.78, $p = 0.01$).

Conclusions: School-based interventions which aim to increase MVPA in adolescent males were not effective. Interventions focused on MBSE demonstrated small to moderate effects. Traditional and plyometric methods of MBSE appear to be the most effective form of PA delivery in adolescent males. More quality research is required to assess the impact of MBSE delivered in the school environment in order to inform future intervention design.

Key Points

- Interventions that aimed to increase MVPA in adolescent boys were not effective. However, interventions that aimed to increase MBSE demonstrated small to moderate effects.
- MBSE delivered in a traditional manner, such as weight machines and free weights, may elicit a greater effect when aiming to promote PA in youth than other forms of MBSE delivery.
- Plyometric forms of MBSE delivery evidenced a significant homogenous effect and require further quality research to assess their application in the school environment.

1 Introduction

It is recommended that adolescents engage in a minimum of 60 min of moderate-to-vigorous physical activity (MVPA) per day with additional muscle and bone strengthening exercise (MBSE) 3 times per week [1,2]. A recent systematic review confirmed the associated health benefits of meeting the recommended MVPA guideline [3]. Furthermore, participating in the recommended 3 days of MBSE per week has also been associated with positive physical and mental health benefits in children and young people [4-8]. Despite this evidence, less than 50% of young people in Europe meet the recommended amount of MVPA suggested by the World Health Organisation (WHO) [9]. Moreover, this WHO report demonstrated a decline in PA with age, with 25% of 11-year olds meeting the recommendations, and then a further decline at age 15 with just 16% meeting recommendations. This supports the suggested year on year decline in PA currently witnessed in boys between the ages of 5 and 15, when measured by accelerometry [10]. Furthermore, recent evidence suggests there is a downward temporal trend in muscular fitness among English school children, indicating a lack of activities that support the development of muscular fitness [11]. Muscular fitness is assessed by measuring performance in tests of muscular strength, power and muscular endurance [11]. Lower levels of muscular fitness are associated with the development of non-communicable disease in adolescent populations [12-16]. Moreover, the development of muscular fitness has been correlated with enhanced bone health, enhanced motor skill and decreased fat mass in adolescents [17-19]. The benefits of MBSE are well established, supported by position stands from leading organisations [20,21]. Despite the growing body of literature supporting the benefits of MBSE, it is often the overlooked element of PA guidelines. Recent UK estimates for health care costs associated with muscle weakness, defined by low grip strength according to the Foundation for the National Institutes of Health criteria (men < 26 kg, women < 16 kg), exceed £2.5 billion [22]. Furthermore, the United States reported estimated health care costs associated with muscular weakness at \$18.5 billion [23]. Poor muscular fitness is associated with sarcopenia, poor quality of life, loss of functional movement

and increase the likelihood of contracting a noncommunicable disease [24]. The associated health care costs and accompanying pathologies supports the need to address the downward trend in muscular fitness currently witnessed in youth.

The school environment has been shown to be effective in the promotion of PA in adolescents [25]. Adolescents are most active during the school day compared to evenings and weekends [26]. Additionally, the school environment provides access to PA independent of background or socioeconomic status [27]. This may expose adolescents to varying forms of PA that they may not have been exposed to outside of school. However, the efficacy of school-based interventions investigating PA in adolescent males is unclear. Much of the existing research and policy to promote PA is directed towards adolescent girls, suggesting that males are at low risk of not meeting the suggested PA levels indicative of good health [28-31]. Although much effort has gone into supporting PA in girls, boys are reported to be at greater risk of becoming overweight or obese, compromising short and long term health [32-35]. In England, recent national surveillance data suggests adult males are more likely to be overweight when compared to adult females [36]. Additionally, worldwide trends in BMI are increasing year on year, with Asia displaying a period of acceleration [37]. For male adolescents, healthy behaviours catalysed during adolescence are often carried into adulthood, supporting the need to investigate the efficacy of current interventions [38].

It is hypothesised that male adolescents may respond more favourably towards MBSE as these activities are perceived as masculine [39,40]. Furthermore, existing evidence supports the role of MBSE interventions for improving physiological and psychological health [4,41,42]. Additionally, appropriate forms of MBSE may engage overweight or obese adolescents [43]. Implementing effective MBSE interventions into the school environment may allow overweight and obese individuals to excel by taking advantage of their relatively greater absolute strength, indicative of a higher fat mass [43]. Therefore, MBSE may be a way of increasing PA levels and improving health among overweight or

obese adolescents. However, MBSE is often an overlooked element of PA guidelines when considering the development of school-based interventions and requires contextualisation.

When exploring the existing literature that reports on the efficacy of MVPA interventions across both sexes and age ranges, mixed outcomes have been reported with small changes of around 4 min per day following school-based interventions [44]. However, it is still not clear how adolescent males respond to both MVPA and MBSE school-based interventions. To the authors' knowledge, this review is the first to investigate the efficacy of school-based PA interventions to improve MVPA and MBSE outcomes in adolescent males. Recent systematic reviews and meta-analyses have investigated MVPA or MBSE exclusively and may have overlooked the efficacy of these PA constructs when analysed together. This systematic review and meta-analysis will include studies that (1) represent adolescent males and report MVPA or MBSE outcomes; and (2) determine the efficacy of MVPA and MBSE interventions delivered in school-settings. The purpose of this systematic review and meta-analysis is to investigate the efficacy of school-based interventions on MVPA and MBSE outcomes in adolescent males.

2 Methods

2.1 Protocol and Registration

This systematic review and meta-analysis were registered with PROSPERO on 15th March, 2018 (Registration number: CRD42018091023). The protocol is published online (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=91023) and follows the PRISMA statement for reporting systematic reviews and meta-analyses.

2.2 Search Procedure

A systematic search was conducted in April 2018 using three electronic databases (PubMed, SPORT Discus and Science Direct). A grey literature search of Google Scholar was also conducted to minimise publication bias [45]. Journal articles published in English post May 2010 until the date of the final search in August 2018 were considered for review. May 2010 was chosen as the initial reference point in order to capture all interventions conducted, following the publication of the WHO PA guidelines [1]. The search strategies for each database are detailed in Table S1 as supplementary information, with a link to one of the database searches as per PRISMA guidelines. The PRISMA flow diagram detailing the procedure can be found in Fig. 1. Reference lists of relevant articles, including systematic literature reviews, were examined for potential articles which fitted the criteria. Two other systematic reviews that reflect the target interventions for this review were also checked for any further literature [4, 46]. All search results were exported to a reference manager, Covidence (<https://www.covidence.org>; Covidence, Melbourne, Australia), allowing for central reviewing and collection of all texts for screening.

Figure 1. PRISMA flow diagram to show each stage of the systematic eligibility process.

2.3 Study Selection

Studies were eligible if they contained an intervention where the main purpose was to promote adolescent male PA in the school environment, with the primary outcome of increasing objectively measured MVPA or MBSE. Included studies investigated adolescent boys aged 10-18 years. Mixed male and female data were acceptable if sex-specific results were available and/or accessible. Studies must have been conducted in a school or college between 8am-6pm on week days during term-time. Studies were included if MVPA and/or MBSE measures were taken at baseline and at the end of the intervention. MVPA studies were only included if MVPA was measured using accelerometers. Girls, community interventions, elite sport, thesis/dissertations, and studies not using accelerometers were

excluded. MBSE measurement methods had to conform to recognised protocols including field-based measures such as press-ups, or the FitnessGram protocol.

Studies could be randomised or non-randomised. Research studies published before 2010 were excluded as were studies that were not published in English. Where full texts were not readily available and where only partial data were reported, the study authors were contacted and asked to provide the full text version with the accompanying data in full. If no response was received after an eight-week follow-up reminder, these studies were excluded as they could not be fully assessed for eligibility. A total of 43 authors were contacted to provide further data and full texts. From the authors contacted, 8 non-responses were recorded, with a further 5 authors unable to provide further data for analysis.

2.4 Data Extraction and Risk of Bias

All search results were exported into Covidence (<https://www.covidence.org>; Covidence, Melbourne, Australia) and duplicates were removed. The first author (AC) screened all titles and abstracts for obvious irrelevance, 10% were also checked by another author (RN). The 10% screening figure is a recognised validation and agreement threshold for systematic reviews [47]. The full-text of eligible studies were then located and reviewed by two authors (AC and RN). Any disagreements were resolved in a meeting involving three authors (AC, RN, and SF). Included studies were assessed for risk of bias using a modified tool [48,49] appropriate for PA reviews which included measures for quantitative studies.

2.5 Data Synthesis and Analysis

Random effects meta-analyses were conducted using Comprehensive Meta-analysis Software (Version 2.2.064). A random effects model was considered more appropriate for this review to account for the expected heterogeneity between PA measures [50]. Hedges' g with 95% CIs were used

to calculate effect sizes [51]. Pooled weighted standard deviations were used as per the Hedge's g formula and based on a positive effect direction for both MVPA and MBSE interventions [51]. Hedges' g was interpreted using Cohen's [51] effect sizes, as small (0.2), medium (0.5) and large (0.8). Heterogeneity was assessed using I^2 statistic, with values of 25, 50 and 75 representing low, medium, and high heterogeneity, respectively [52]. Publication bias was assessed using Egger's statistic, where bias was deemed to be present at $p = <0.05$ [53]. Corresponding funnel plots were created for visual interpretation, followed by calculating Egger's statistic to confirm or refute publication bias.

2.6 Quality Appraisal

Included studies were assessed for risk of bias using a modified tool suitable for PA interventions [48,49]. The ability to distinguish the nature of the PA outcome assessment method, in addition to the existent randomisation, blinding, and complete outcome data items was accounted for within this tool. This adapted quality assessment tool used a 1-4 scoring system (i.e., 1 = weak and 4 = very strong; see Table 1.

Table 1. Quality assessment (Risk of Bias)

Study	Appropriate sequence generation and/or randomisation	Allocation concealment and/or blinding	Complete outcome data and/or low withdrawal/drop-out (<20%)	Appropriate outcome measure (PA)	Quality Score
1. Azevedo et al. (2014)				X	*
2. De Souza et al. (2015)			X	X	**
3. Eather et al. (2016)	X	X	X	X	****
4. Giannaki et al. (2016)		X	X	X	***

5. Ha et al. (2017)	X	X	X	X	****
6. Kennedy et al. (2018)	X		X	X	***
7. Lloyd et al. (2012)			X	X	**
8. Lloyd et al. (2016)			X	X	**
9. Lonsdale et al. (2013)	X	X	X	X	****
10. Lubans et al. (2016)	X	X		X	***
11. Muehlbauer et al. (2012)			X	X	**
12. Muntaner-mass & Palou. (2017)			X	X	**
13. Weeks & Beck. (2012)			X	X	**
14. Weston et al. (2016)				X	*
15. Winwood & Buckley. (2017)			X	X	**

3 Results

Extracted studies were conducted in eight different countries (UK, Brazil, Australia, Cyprus, Hong Kong, Germany, Spain, and New Zealand) [54-68]. The studies included displayed no obvious bias, but rather a lack of depth and detail, which made the risks of bias difficult to detect. Details regarding sequence generation and allocation concealment and/or blinding were found to be the categories that were often not sufficiently reported on. Thirty-three percent of the studies reported an appropriate sequence generation or randomisation in detail [56,58,59,62,63], with a further 33%

reporting allocation concealment or blinding in detail [56,57,58,62,63]. This may suggest selection and reporting bias in the literature. Complete outcome data and/or low dropout rates were present in 73% of the included studies and can therefore be interpreted as having low risk of bias as a result of attrition. Risk of bias through inappropriate outcome measures was not an issue for this review as all studies selected had to demonstrate an objective way of assessing MBSE and /or MVPA.

Of the 15 studies that were included, 6 investigated MVPA, providing 8 data sets [54,58,59,62,63,67]. A further 43 data sets were extracted from 11 studies [55,56,57,59,60,61,63,64,65,66,68] for muscle and bone strengthening, with studies reporting multiple MBSE outcomes including a combination of upper and lower limb measures. Upper and lower limb data sets were analysed independently to identify possible intervention effects. Further subgroup analyses of MBSE interventions were conducted, accounting for: bodyweight movements (i.e., push ups and curl ups), combined activities (i.e., circuit-based activities), plyometrics, and traditional methods such as weight machines and free weights. Participants' ages ranged from 11.0-16.9 years, with a total sample size of 1547 participants for intervention groups and 1490 participants for control groups. These samples were separated into, MVPA control (n = 326), MVPA Intervention (n = 295), MBSE control (n = 1164) and MBSE intervention (n = 1252). A full breakdown of how sample sizes were extracted is provided in Table. 2. Identification of possible publication bias was plotted against standard errors to generate funnel plot (Fig 2). Egger's analyses for all data sets suggested that publication bias was not present ($p > 0.05$).

Figure 2. Funnel plot of standard error by Hedge's g.

Table 2. Characteristics of MVPA and MBSE studies included in this systematic review. Letters a-l relate to individual outcome measures and are displayed in subsequent forest plots.

Study & Quality Rating	Country	Participants	Intervention Duration and Measurement Period	PA Measurement Method & PA Outcome Measure
Azevedo et al. (2014) *	UK	Total: n = 99 Mean age: 11-13 Control: n = 48 Intervention: n = 51	12 months with measurements taken at baseline and post intervention	MVPA Participants were asked to wear a physical activity monitor (Actigraph GT3X, DynaPort MiniMod (MiniMod)) around the hip during waking hours (except during water-based activities) for seven consecutive days. To detect the intermittent bouts of moderate to vigorous physical activity data were recorded in 10 second epochs. Data were only processed for participants with wear-times of at least 10 hours per day on at least three days.
De Souza et al. (2015) **	Brazil	Total: n = 19 Mean age: 12.8 ± 0.6 Control: Mass: (Kg) 54 ± 10	12 weeks, completing 2 60 minute sessions per week.	Muscle/ Bone Strengthening a) Horizontal Jump (HJ): The subjects performed the horizontal jump test. The best distance (in centimetres) of three attempts was recorded.

		Height: (m) 1.57 ± 0.7 BMI: 22 ± 3 Intervention: Mass: (Kg) 52 ± 9 Height: (m) 1.60 ± 0.8 BMI: 20 ± 2		b) Push-Ups (PUS) in 1 min: The subjects performed the maximum number of repetitions of PUS in 1 min. c) Curl ups (CUR): The subjects performed the maximum number of repetitions of CUR in 1 min.
Eather et al. (2016) ****	Australia	Total: n = 46 Mean age: 15.3 ± 0.47 Mass: (Kg) 65.1 ± 12.3 Height: (m) 1.77 ± 0.72 BMI: 21.3 ± 3.4 Control: n = 22 Intervention: n = 24	8 weeks, completing 2 60 minute sessions per week.	Muscle/ Bone Strengthening a) Push up tests (reps) b) Curl up test (reps) c) Standing jump (m) d) Grip strength (Kg) FitnessGram protocol
Giannaki et al. (2016) ***	Cyprus	Total: n = 39 Mean age: 16 Control: n = 19 Mass: (Kg) 59.4 ± 13.7 Height: (cm) 169.3 ± 8.9 BMI: 20.5 ± 2.9. Intervention: n = 20 Mass: (Kg) 64.5 ± 13.0 Height: (cm) 169.8 ± 6.4 BMI: 22.3 ± 3.7	8 weeks, completing 2 sessions per week.	Muscle/ Bone Strengthening a) Hand grip strength (Kg) left b) Hand grip strength (Kg) right c) Vertical jump (cm)

Ha et al. (2017) ****	Hong Kong	Total: n = 77 Mean age 14.38 ± 0.82.	15 minute skipping rope activity across 3 classes ranging from 45-90 minutes long.	MVPA ActiGraph GT3X
Kennedy et al. (2018) ***	Australia	Total: n = 303 Control: n = 124 Mean age: 14.2 ± 0.5 Intervention: n = 179 Mean age: 14.1 ± 0.4	10-wk school term, with pre-test and post-test data collection occurring in the preceding and ensuing school terms to the intervention, respectively (i.e., pre-tests occurred in term 2 (April–June), the intervention was delivered in term 3 (July–September), and post-test occurred during term 4 (October–December)). This resulted in an approximate period of 6 months between pre-test and post-test measurements.	Muscle/ Bone Strengthening a) Push ups (reps) b) Standing long jump (m) MVPA c) Physical activity was assessed using GENEActiv wrist-worn accelerometers (Model GAT04; Activinsights Ltd, Cambridgeshire, England, UK) in a random subsample of participants. This random sample was chosen by allocating accelerometers to 50% of the students present on the day of testing (i.e., students were stratified by sex and allocated ID numbers, with every odd numbered student receiving an accelerometer). Analyses for weekday MVPA included participants who wore their monitor for ≥600 min/day on at least three weekdays.
Lloyd et al. (2012) **	UK	Total: n = 109 Control 1: n = 22 Mean age: 12.23 ± 0.28	4 weeks of 2 x sessions per week. Measurements taken pre and post intervention	Muscle/ Bone Strengthening Reactive Strength Index (millimetres per millisecond). Reactive strength index (RSI) was determined during the maximal hopping test, which involved the participants performing 5 repeated bilateral maximal vertical hops on the contact mat. The

		<p>Mass: (Kg) 47.38 ± 13.91 Height: (cm), 151.67 ± 6.93</p> <p>Intervention 1: n = 22 Mean age: 12.29 ± 0.31 Mass: (Kg) 44.78 ± 9.42 Height: (cm) 151.89 ± 7.94</p> <p>Control 2: n = 24 Mean age: 15.29 ± 0.33 Mass: (Kg) 63.70 ± 11.43 Height: (cm) 174.11 ± 9.20</p> <p>Intervention 2: n = 20 Mean age: 15.33 ± 0.27 Mass: (Kg) 64.96 ± 8.89 Height: (cm) 174.35 ± 6.63</p>		<p>participants were instructed to maximize jump height and minimize ground contact time. The first jump in each trial was discounted, whereas the remaining 4 hops were averaged for the analysis of RSI.</p> <p>a) Intervention 1, pre peak height velocity</p> <p>b) Intervention 2, post peak height velocity</p>																
Lloyd et al. (2016) **	UK	<p>Total: n = 80 (n = 40 pre-PHV, n = 40 post-PHV).</p> <p>Participants were divided into 4 groups, plyometric training, traditional strength training,</p>	<p>2 sessions per week for 6 weeks.</p> <p>Measurements taken pre and post intervention</p>	<p>Muscle/ Bone Strengthening</p> <p>Squat Jump Height (cm)</p> <table><tr><td>Pre PHV</td><td>Post PHV</td></tr><tr><td>Plyometric training: a.</td><td>d</td></tr><tr><td>Traditional strength: b.</td><td>e</td></tr><tr><td>Combined training: c.</td><td>f</td></tr></table> <p>Reactive Strength Index (millimetres per millisecond)</p> <table><tr><td>Pre PHV</td><td>Post PHV</td></tr><tr><td>Plyometric training: g.</td><td>j</td></tr><tr><td>Traditional training: h.</td><td>k</td></tr><tr><td>Combined training: i.</td><td>l</td></tr></table>	Pre PHV	Post PHV	Plyometric training: a.	d	Traditional strength: b.	e	Combined training: c.	f	Pre PHV	Post PHV	Plyometric training: g.	j	Traditional training: h.	k	Combined training: i.	l
Pre PHV	Post PHV																			
Plyometric training: a.	d																			
Traditional strength: b.	e																			
Combined training: c.	f																			
Pre PHV	Post PHV																			
Plyometric training: g.	j																			
Traditional training: h.	k																			
Combined training: i.	l																			

		combined training and control.		
Lonsdale et al. (2013) ****	Australia	Total: n = 145 Mean age: 13.6	3 months. Measurements taken at Baseline and post-intervention data were collected from all participating students, regardless of study arm, during and immediately after two 20-min segments of PE lessons. In between these two lessons, teachers received a brief intervention (three experimental arms) or were asked to continue with usual practice (control arm).	MVPA ActiGraph GT3X (ActiGraph; Pensacola, FL) were used to assess PA levels (percentage of time spent in MVPA and percentage of time spent sedentary) of each student in this study. Monitors were synchronized with an external clock and initialized to start recording data in three axes of motion in 1-sec epochs, a minimum of 30 min before and after the scheduled PE lessons. a) Relevance b) Providing Choice c) Free Choice
Lubans et al. (2016) ***	Australia	Total: n = 361. Control: n = 180 Mean age: 12.7 ± 0.5 Mass: (Kg) 53.1 ± 13.4 Height: (cm) 160.2 ± 8.4 BMI: 20.5 ± 4.1	20 weeks, 20 x 90 minute sessions delivered by teachers during school sport periods in addition to regular PE. Lunch time sessions run by students, 6 x 20 minute sessions.	Muscle/ Bone Strengthening a) Push up test, FITNESSGRAM protocol. b) Handgrip strength (Kg) MVPA ActiGraph GT3X. To be included for analysis wear time ≥480 mins per day. MVPA calculated using Evenson cut points. Reported as %.

		Intervention: n = 181 Mean age: 12.7 ± 0.5 Mass: (Kg), 54.0 ± 15 Height: (cm) 160.9 ± 9.0 BMI: 20.5 ± 4.1	Measurements taken at baseline, 8 months and 18 months.	
Muehlbauer et al. (2012) **	Germany	Total: n = 13 Control: n = 7 Mean age: 16.9 ± 0.7 Mass: (Kg) 66.7 ± 7.5 Height: (cm) 182.6 ± 6.3 BMI: 20 ± 2.0 Intervention: n = 6 Mean age: 16.8 ± 0.8 Mass: (Kg) 68.8 ± 2.6 Height: (cm) 181.8 ± 6.5 BMI: 21.1 ± 1.7	8 weeks, 2 sessions per week. Measurements taken at pre and post intervention	Muscle/ Bone strengthening a) Maximal isometric force, leg press b) Rate of force development, leg press c) Counter-movement jump height
Muntaner-mass & Palou. (2017) **	Spain	Total: n = 83. Control: n = 35 Mean age: 15.8 ± 0.5 Mass: (Kg), 64.0 ± 10.8 BMI: 21.1 ± 3.0 Intervention: n = 45 Mean age: 15.9 ± 0.6	5 months, 2 sessions per week. Measurements taken at pre and post intervention.	Muscle/ Bone strengthening a) Hand grip strength (Kg) left b) Hand grip strength (Kg) right c) Standing broad jump (cm)

		Mass: (Kg) 64.7 ± 12.0 BMI: 21.4 ± 3.3.		
Weeks & Beck. (2012) **	Australia	Total: n = 46. Control: n = 24 Mean age: 13.8 ± 0.4 : Mass: (Kg) 58.6 ± 16.7 Height: (m) 1.640 ± 0.086 BMI: 20.5 ± 4.3 Intervention: n = 22 Mean age: 13.8 ± 0.4 Mass: (Kg) 55.0 ± 13.8 Height: (m) 1.637 ± 0.098 BMI: 20.3 ± 3.6.	8 months, 2 sessions per week consisting of 10 minutes. Measurements taken at pre and post intervention.	Muscle/ Bone Strengthening Vertical jump (cm)
Weston et al. (2016) *	UK	Total: n = 63 Control: n = 30 Mean age: 14.2 ± 0.3 Mass: (Kg) 57.2 ± 10.2 Height: (cm) 166.0 ± 6.9 BMI: 20.5 ± 2.9. Intervention: n = 33 Mean age: 14.8 ± 0.2 Mass: (Kg) 60.2 ± 15.8	The intervention comprised 4 to 7 repetitions of 45 s maximal effort exercise (basketball, boxing, dance and soccer drills) interspersed with 90-s rest, thrice weekly for 10 weeks	MVPA Physical activity was measured via Actigraph GT1M accelerometers (Actigraph, LLC, Pensacola, Florida), which were initialised to collect data at 10-s epochs using ActiLife software (Version 5.8.3). Participants were instructed to wear their device on their right hip during all waking hours, except when engaging in water-based activities, for seven consecutive days prior to the intervention, and for seven days after the intervention finished

		Height: (cm) 166.9 ± 7.2 BMI: 21.3 ± 4.3		
Winwood & Buckley. (2017) **	New Zealand	Total: n = 62 Control: n = 23 Mean age: 14.3 ± 0.5 Mass: (Kg) 63.2 ± 13.2 Height: (cm) 174.1 ± 8.7 Intervention (Bodyweight and mobility): n = 25 Mean age: 14.2 ± 0.4 Mass: (Kg) 64.4 ± 12.2 Height: (cm) 175.2 ± 8.1 Intervention (Combined bodyweight, mobility and free weight resistance): n = 14 Mean age: 14.3 ± 0.5 Mass: (Kg) 61.8 ± 13.1 Height: (cm) 174.0 ± 9.6	7 weeks, 2-3 sessions. Measurements taken at -1 and +2.	Muscle/ Bone Strengthening Push up tests (reps) a) Bodyweight and mobility b) Bodyweight, mobility and weight resistance Horizontal jump (m) c) Bodyweight and mobility d) Bodyweight, mobility and weight resistance Medicine ball throw (m) e) Bodyweight and mobility f) Bodyweight, mobility and weight resistance Counter movement jump (m) g) Bodyweight and mobility h) Bodyweight, mobility and weight resistance

3.1 Pooled Analysis

Figure 3 illustrates effect sizes for all MVPA and MBSE intervention studies. Studies covering more than one aspect of the guidelines or multiple interventions were analysed and reported separately. Effect sizes ranged from 0.06 to 0.37 indicating small to medium intervention effects relative to the respective control. The effect size for all studies investigating MVPA and MBSE outcomes was small ($g = 0.26$, 95% CI = 0.15, 0.37, $P = <0.00$). Based on the established thresholds, high heterogeneity was present when pooling all PA interventions together ($I^2 = 75.39$). This heterogeneity was expected due to the broad and varied measures of monitoring PA outcomes and the variety of interventions that were conducted to target MVPA and MBSE.

Figure 3. Individual study, individual measure and pooled results of MVPA and MBSE outcomes.

3.2 Moderate to Vigorous Physical Activity

MVPA interventions were evidenced as ineffective ($g = -0.09$, 95% CI = -0.72, 0.53, $P = 0.77$). Although only eight data sets were utilised, the studies displayed high heterogeneity ($I^2 = 92.49$). Three of the data sets came from the same study investigating three different psychological strategies to promote MVPA and were analysed independently within this meta-analysis [62]. Two outliers were removed, which reduced heterogeneity ($I^2 = 47.12$), but did not impact on effect size estimates ($g = 0.00$, 95% CI = -0.26, 0.27, $P = 0.96$). The corresponding forest plot can be seen in Fig. 4.

Figure 4. Individual study and pooled results of MVPA outcomes with outliers removed.

3.3 Muscle and Bone Strengthening Exercise

MBSE interventions demonstrated a small to medium effect ($g = 0.27$, CI 0.16, 0.39, $P = <0.00$). Low to medium heterogeneity was present amongst the 43 data sets ($I^2 = 38.27$). The 43 data sets came from 11 studies accounting for different MBSE outcomes and measures within each intervention.

3.4 Upper and Lower Limb Activities

MBSE interventions were separated into those that focused exclusively on upper limb ($n = 14$) and lower limb activities ($n = 27$). Two data sets measuring core strength were omitted from the analysis as this number was insufficient. Upper limb interventions presented a small to medium effect, with moderate heterogeneity evident ($g = 0.23$, 95% CI 0.03, 0.43, $p = 0.02$, $I^2 = 64.75$). Lower limb interventions displayed little heterogeneity ($I^2 = 0.00$) and elicited a small to medium effect ($g = 0.21$, 95% CI 0.09, 0.33, $p = <0.00$). The corresponding forest plot can be seen in Fig. 5.

3.5 Combined Muscle and Bone Strengthening Activities

Combined activities (CA) consisted of those interventions that incorporated multiple methods to enhance MBSE ($n = 21$). These interventions took the form of circuit training style delivery. There was a small effect for these interventions ($g = 0.22$, 95% CI 0.05, 0.39, $p = <0.00$), which had moderate heterogeneity ($I^2 = 61.81$).

3.6 Plyometric Activities

Plyometric forms of training ($n = 6$) resulted in a small to moderate effect size ($g = 0.39$, 95% CI 0.09, 0.68, $p = 0.01$). Analysis of heterogeneity demonstrated that plyometric forms of training were homogeneous ($I^2 < 0.00$).

3.7 Body Weight Activities

Interventions utilising body weight (BW) as the resistance elicited a small effect ($n = 9$, $g = 0.21$, 95% CI -0.00, 0.44, $p = 0.05$). Analysis demonstrated low heterogeneity ($I^2 = 10.17$) for all studies utilising BW.

3.8 Traditional Methods

Traditional methods (TM) were deemed to be those methods that utilised free weights and resistance machines [69]. TM indicated a small to medium effect ($n = 7$, $g = 0.43$, 95% CI -0.09, 0.78, $p = 0.01$). TM displayed low heterogeneity ($I^2 = 0.00$) and the greatest effect size in relation to the control groups. The entire breakdown of MBSE subgroups is presented in Fig. 6.

Figure 5. Individual and pooled sub-group analyses of upper limb and lower limb MBSE outcomes.

Figure 6. Individual and pooled sub-group analyses of MBSE delivery method.

4.0 Discussion

To date the literature has primarily focussed on the MVPA aspect of the PA guidelines, often overlooking MBSE [70]. Furthermore, adolescent males are underrepresented in the literature relative to females [71]. When school-based PA interventions were pooled together, a small intervention effect was evident. Studies investigating MVPA were not found to be effective in adolescent males and demonstrated high heterogeneity. Our findings support a recent systematic review investigating MVPA levels in isolation during PE [46]. However, this review expands on previous findings by investigating MVPA across the whole school day beyond the delivery of PE. Furthermore, this review builds upon the current literature by investigating the MBSE construct of PA. Our findings demonstrated that studies investigating MBSE were effective, which concurs with current literature suggesting adolescent males may be receptive to MBSE interventions [72]. However, the small to moderate findings of this review should be approached with caution and considered in light of the high heterogeneity and potential for publication bias. Overall, these data are consistent with the notion that adolescent males present a challenge when conducting school-based PA interventions. Adolescent boys that are overweight, obese, currently inactive, and from a low socioeconomic prevalence may be less likely to comply with accelerometer protocols [73], and this may have impacted the outcome of this review. Qualitative research may help further understand the lack of compliance and offer viable solutions to overcoming the challenges evidenced when working with adolescent boys.

The literature suggests MBSE interventions lasting 8 to 12 weeks are most effective in adolescent populations [74-76]. Seventy-two percent of studies investigating MBSE interventions met or exceeded this, suggesting that intervention duration may not have been long enough in over a quarter of studies to evoke an efficacious response. It is acknowledged that MBSE must adhere to underlying physiological characteristics that affect muscular strength in order to elicit an efficacious response and/ or adaptation [77]. Furthermore, the development of strength is underpinned by a combination

of neural and morphological factors that may not be specifically catered for by conducting combined activities that involve high intensity circuit-based interventions [77]. Adolescence provides an opportunity for neural and architectural adaptations in the development of strength due to increases in anabolic and hormonal concentrations [78]. However, 21 of the 43 data sets investigating MBSE utilised combined activities and may have overlooked the existing evidence-based methods that elude a more favourable response to the development of MBSE, such as specific set and repetition schemes combined with appropriate rest periods. However, the practicalities, compliance and pedagogical considerations associated with designing an MBSE programme have not been explored in the literature and may explain the lack of clarity on appropriate MBSE intervention design for a school-based setting.

Interestingly, plyometric MBSE demonstrated a statistically significant, homogenous effect. Plyometric training has been evidenced to benefit peak bone mass in adolescent girls [79], evidence in male adolescents is currently lacking but may elicit similar responses. However, only 2 studies adhered to appropriate plyometric training protocols, supporting the need for further quality research in this method of MBSE. Plyometric forms of training show promise and may provide a way to enhance muscle and bone strength. However, if such protocols are to be utilised within a school-based environment, appropriate training must be provided to ensure the safety and efficacy of this mode of MBSE. Moreover, individual variability in biological age, training age, skill and coordination will dictate prescription of training frequency, intensity, velocity and, volume of plyometric MBSE [80]. The complexities associated with plyometric MBSE may explain the lack of research. Furthermore, consideration to pedagogy and practical application beyond the research in a school-based environment requires further investigation.

A key finding of this analysis was that traditional methods of MBSE were most effective. These are similar to those commonly practiced in commercial gymnasium environments that adolescents may

encounter after leaving school. Thus, exposure to traditional MBSE may allow for preparation towards the transition into a popular form of PA conducted by adults. Recommendations for loading protocols can expect to see loads of 5-10% added once the individual can comfortably perform 15 repetitions of a given movement with good form [81]. This method of adding load to progress the intensity of the MBSE may allow for greater perceived autonomy, whilst ensuring load increases are controlled. Moreover, allowing individuals to regulate the load progressions may enhance the intrinsic appeal [82]. Furthermore, the potential for enhancing physical literacy through neuromuscular adaptation indicative of MBSE may allow for previously disengaged adolescents to enhance their competence and participate in PA with greater intent and vigour. Collectively, this greater involvement and ability to exercise competently alongside their peer group may allow for the relatedness component of self-determination theory (SDT) to be satisfied. Further research is warranted and should investigate SDT as a psychological construct to intervention design.

Subgroup analyses evidenced MBSE elicited a homogenous small to medium effect. However, these results should be interpreted with caution as 7 different measures to assess lower limb strength were used throughout the studies. Future research should standardise the use of lower limb strength measurements in order to assess and contextualise the efficacy of lower limb MBSE. Conversely, methods of assessing upper limb strength were consistent across all 10 studies. Press ups and grip strength featured in five and four of the studies respectively, with one study assessing medicine ball throw. However, grip strength for upper limb assessment may not be the most reflective of those movements conducted during everyday life or as part of an exercise training regime [83]. Recently, back leg and chest dynamometry has been validated in adolescents and may provide a cost effective, mobile and simple tool to assess overall limb strength [84]. To date, no school-based interventions investigating MBSE have utilised back leg and chest dynamometry as a measure to assess overall limb strength. Future research should consider the use of back leg and chest dynamometry to provide a measure of overall strength that may be more aligned to everyday life and as a marker of health [84].

Only 2 studies objectively measured trunk strength. Trunk strength measures are simple to conduct and may inform the health of the lower back [85]. Although measures of trunk strength are simple to conduct in a field-based setting, researchers may be discouraged by the lengthy familiarisation process [86]. Researchers should explore methods that support a reduced familiarisation period or introduce familiarisation methods before intervention and data collection.

This review found that MVPA studies were less effective when compared to studies targeting MBSE outcomes. Difficulties investigating adolescent males in a school-based environment were evident, with 3 data sets reporting incomplete data and/or dropout rates of >20%. MVPA interventions within this analysis did not undergo subgroup analysis due to the lack of studies reporting subgroup data (e.g., weight status, socioeconomic status). Although 8 data sets were identified investigating MVPA, 3 of the data sets came from 1 study [63], which further demonstrates the underrepresentation of adolescent males within the current literature.

Although there is a lack of research targeting MVPA in adolescent males, one study showed promise delivering a high intensity interval training (HIIT) protocol [67]. The study demonstrated a positive effect in relation to the control group ($g = 1.70$, 95% CI 0.57, 2.83). However, the HIIT study may have experienced selection bias and the authors acknowledged that lack of randomisation may have impacted the results. Furthermore, the HIIT study reported a lack of participants meeting accelerometer wear time criteria, resulting in data attrition >20%. Although the study was rated as weak in the quality assessment, HIIT interventions warrant further investigation. HIIT training has grown in popularity as a mode of life long PA, as it is time efficient whilst also promoting favourable adaptations in physical fitness [87]. A recent meta-analysis exploring HIIT, reported favourable changes in cardiorespiratory fitness and body composition in adolescents [87].

Interestingly, MVPA interventions investigating student involvement in the decision-making process showed a positive effect alongside traditional methods of PE delivery [63]. Of the 3 data sets from this study included in this review, 1 demonstrated a small to medium effect size ($g = 0.44$, 95% CI -0.02, 0.91) and provided the students with “free choice” during their PE lessons. The delivery of this intervention was carried out by teachers, allowing the students to conduct PE under their supervision, but without instruction. Future research should explore the role of autonomy as a construct to promoting motivation and healthy psychological and behavioural functioning, which may be achieved through involving adolescents in the decision-making process. SDT may provide a psychological construct that allows future research to facilitate autonomy whilst addressing additional factors of psychological well-being that are indicative of basic psychological needs. The lack of psychological underpinning for interventions promoting MVPA may be a reason for the evidenced ineffectiveness within adolescent males. Additionally, future intervention design may benefit from exploring enhanced, extended and expanded opportunities (TEO) for youth PA in conjunction with complex behavioural theories [88]. TEO allows for a pragmatic approach to intervention design, expanding on PA opportunity by adding to the current PA opportunities, extending PA by adding additional time to current PA opportunities and, enhancing PA by augmenting existing PA opportunities [88]. Addressing both TEO and motivational psychological constructs may enhance the quality of the PA experience and positively impact intervention outcomes [88].

5.0 Strengths of this Review and Meta-analysis

To the authors’ knowledge this review is the first to address the efficacy of school-based adolescent male MVPA and MBSE interventions. This systematic review and meta-analysis are novel by way of addressing MVPA and MBSE outcomes which are elements of youth PA guidelines. This review only included objective measures and did not include those studies that utilised PA questionnaires. Past research has shown that misreporting of PA levels in around 50% of adolescents [89] and the

possibility of misinterpretation for PA questionnaires [90]. With evidence suggesting that questionnaires and the reporting of PA levels may not be accurate, such data was negated from this systematic review and meta-analysis. The process to locate and extract all relevant data was rigorous and utilised an experienced librarian to ensure a comprehensive search strategy. Contact with authors requesting further information was made across three platforms (Email, ResearchGate and Twitter) to ensure data could be captured. A large sample size was used following breakdown of the markers of MBSE and MVPA (n = 3037).

6.0 Limitations and Recommendations for Future Research

There are limitations to this study that should be considered when interpreting the results. Although a large sample size was acquired, only 20.4% consisted of MVPA interventions. Varying PA measurement methods were also used during interventions to elicit changes in MVPA. Furthermore, continuity of assessment method for MBSE interventions varied greatly, especially in LL. The way in which training regimes were administered may also impact the outcome within the interventions, it is well understood that the end result of MBSE is determined by how the intervention is delivered and further research should seek to contextualise this to appropriately inform future practice [77]. Future research should investigate how differing MBSE delivery impacts the efficacy and outcome of the intervention. MVPA interventions also vary in their delivery, from HIIT to game based and dance mat constructs. Methods of MVPA delivery warrant further investigation within this population group, specifically those methods indicative of LLPA such as HIIT, jogging and cycling. The impact of psychological health, motivation and perceptions should also be accounted for in the development of future interventions. Attempts should be made to address the concerns of adolescent males reported within the literature, with a third reporting a desire to enhance muscular aesthetics and another third reportedly wanting to become leaner [91,92]. Furthermore, it has been hypothesised that adolescent males may be more inclined to participate in MBSE activities that are deemed more masculine [39].

Future research should standardise MBSE assessment methods for use within adolescent population groups. Studies investigating changes in MBSE should consider the whole intervention and how conflicting training modalities may impact MBSE outcomes.

7.0 Conclusions

This systematic review and meta-analysis found a significant small effect for school-based PA interventions in adolescent males. Whilst we can conclude that MVPA interventions were not effective, the results were negligible in terms of their magnitude. Although MVPA is a key element of the current PA guidelines, efforts should be made to investigate the often overlooked MBSE element of the PA guidelines that also support physical and psychological health. Traditional methods of MBSE demonstrated the greatest effect when compared to other forms of MBSE, such as body weight movements and require further research to draw more generalisable conclusions to inform long term intervention design.

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