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Efficacy of school- based interventions for improving muscular fitness outcomes in children: A systematic review and meta- analysis

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Abstract

The World Health Organization recommends that children should engage in an average of 60 minutes of moderate-to-vigorous physical activity (MVPA) per day and should perform activities that strengthen muscle and bone at least 3 days a week. Public health professionals as well as pediatric researchers have identified schools as a strategic place to promote muscular strength development. Thus, the aim of this systematic review and meta-analysis was to investigate the efficacy of school-based exercise interventions for improving muscular fitness (MF) in children. Searches were conducted in three databases. Eligible criteria were randomized and non-randomized controlled trials evaluating the effects of school-based exercise interventions on MF (i.e., muscular strength, muscular power, and local muscular endurance) in children under 13 years of age. Risk of bias by the National Institutes of Health tool was appraised, and pooled effect sizes (Hedges'g) were calculated using random-effects inverse-variance analyses.

Seventeen studies enrolling 1653 children (28% girls were analyzed). Exercise interventions, mostly combined interventions targeting selected domains of MF, were associated with significant moderate increases in local muscular endurance (g=0.65 95% CI, 0.13 to 1.17, p=0.020; I^2=85.0%) and muscular strength and muscular power (g=0.33 95% CI, 0.16 to 0.51, p=0.001; I^2=59.3%), with higher effects using interventions with ≥3 sessions per week. Our findings indicate that school-based exercise that includes strength building exercises may improve MF in children and, consequently, prepare modern day youth for the demands of exercise and sport activities.

Systematic review registration: PROSPERO CRD42021237323.

Highlights

- School-based muscle and bone strengthening exercises performed at least 3 days per week may serve to support the development of muscular fitness in girls and boys
- Integrative interventions that include a variety of strength and conditioning activities seem to be a promising strategy to promote muscular fitness in school environment
- Future research should standardize MF assessment methods for use with children in the school context and should include interventions with girls
- It is of interest to a growing number of health care providers, fitness professionals and physical education teachers to encourage participation in well-designed muscle and bone strengthening exercises.

KEYWORDS

Physical activity; strength training; school context; youth

Efficacy of school- based interventions for improving muscular fitness outcomes in children: A systematic review and meta- analysis

Introduction

The 2020 update to the World Health Organization (WHO) physical activity (PA) guidelines recommend that children should engage in at least an average of 60 minutes of moderate-to-vigorous physical activity (MVPA) per day and should also perform vigorous intensity aerobic activities, as well as muscle and bone strengthening exercises at least three times per week (Bull et al., 2020). In school-age youth, regular MVPA is associated with improvements in cardiometabolic health, body composition, academic achievement, and health-related quality of life (Piercy et al., 2018). Moreover, regular participation in muscle and bone strengthening exercises is associated with favorable changes in musculoskeletal health, muscular fitness (i.e., muscular strength, muscular power and local muscular endurance) and mental health (Aubert et al., 2018). Despite this evidence, the Global Matrix 3.0 Physical Activity Report Card Grades evaluating a total of 49 countries indicated that only a 34%-46% of children and youth meet the minimum recommendation of at least 60 min of MVPA per day (Aubert et al., 2018).

Since PA behaviors are developed early in life and may persist throughout childhood and adolescence (Telama et al., 1997), adequate PA level in childhood may also be important for the prevention of obesity and chronic diseases later in life (Hjorth et al., 2014). Notably, muscular fitness (MF) phenotypes tend to track from childhood to adulthood, and therefore weak children are likely to become weak adults unless strategies that target strength development are introduced early in life (Fraser et al., 2021).

Low levels of MF in children are associated with poor motor competence, functional limitations and adverse health outcomes (García-Hermoso et al., 2019; Smith et al., 2014). Recent findings indicate that selected measures of MF in modern-day youths are lower than in previous generations (Faigenbaum et al., 2019; Sandercock & Cohen, 2019; Tomkinson et al., 2021). Notably, a study from Australia found that the standing long jump performance of children and adolescents declined a 5.6% and 5.8% in boys and girls, respectively, since 2000 (Tomkinson et al., 2021), and Sandercock and Cohen reported a decline in muscular strength (assessed with the bent-arm hang, sit-ups and handgrip tests) in 10-year-old English children from 1998 to 2014 (Sandercock & Cohen, 2019). Similar secular trends in MF were reported in youth from Slovania (Đurić et al., 2021), Spain (Chulvi-Medrano et al., 2020), New Zealand (Albon et al., 2010) and the United States (Tomkinson et al., 2021). Despite the growing body of evidence supporting the health and fitness benefits of muscle and bone strengthening exercises for school-age youth (García-Hermoso et al., 2019; Lloyd et al., 2014; Smith et al., 2019), the importance of enhancing MF early in life is often overshadowed by general recommendations to accumulate at least 60 minutes of MVPA daily (Faigenbaum et al., 2020).

Opportunities for children to be physically active have declined in many countries in recent decades due to environmental factors, technology, social media and school policies (Organization, 2010). Public health professionals as well as pediatric researchers have identified schools as a strategic place to promote PA as an ongoing lifestyle choice (Bull et al., 2020; Collins et al., 2018; Poitras et al., 2016; Tercedor et al., 2017). Since most children have the emotional maturity to begin participating in sport activities by 5 to 7 years of age, they may also be ready for some type of structured muscle and bone strengthening exercises that is consistent with their needs, abilities and interests (Stricker et al., 2020).

The benefits of muscle and bone strengthening exercises are well established, supported by position stands from leading organizations (Faigenbaum et al., 2009; Lloyd et al., 2014; Stratton et al., 2004). However, a recent systematic review and meta-analysis (Cox et al., 2020) found a significant small effect for school-based MF interventions in adolescent boys. Across the eleven studies included in the aforementioned report (Cox et al., 2020), MSBE that included strength exercises with free weights (barbells and dumbbells) and weight machines and plyometric exercises that included jumps and hops demonstrated the greatest effect when compared to other forms of RT (e.g., body weight exercises). Due to the importance of targeting strength deficits earlier in life with structured programs as well as the observable health and fitness benefits of muscle and bone strengthening exercises on young girls (Faigenbaum et al., 2020; Stricker et al., 2020) , the aim of this systematic review and meta-analysis was to investigate the efficacy of school-based exercise interventions for improving MF in girls and boys under 13 years old.

Materials and methods

This systematic review and meta-analysis were registered in the PROSPERO International Prospective Register of Systematic Reviews on 22th March, 2021 (Registration number: CRD42021237323). We followed the recommendations of preferred reporting items for systematic reviews and meta-analyses (The PRISMA 2020 statement) (Page et al., 2021). The PRISMA (main and abstract) checklist can be found in supplementary materials.

Eligibility Criteria

The study selection protocol was adapted from Cox et al. (Cox et al., 2020). Studies were eligible if they contained an intervention where the main purpose was to promote PA in the school environment, with the primary outcome of increasing objectively measured MF, i.e., those interventions that included muscle and bone strengthening exercises. Included studies investigated healthy girls and boys <13 years old (i.e., mostly in primary school). Reports that involved youth ≥13 years of age were excluded. The selection of this age-based cut-off is mainly since this age criterion is recommended by the International Consensus on Youth Resistance Training (Lloyd et al., 2014). In this consensus, it is clarified that childhood represents the developmental period of life from the end of childhood to the beginning of adolescence (generally up to the age of 11 and 13, respectively for boys and girls) who have not developed secondary sexual characteristics. Studies must have been conducted in a school setting on weekdays (including morning and afternoon hours) during the academic year. All studies included MF measures taken at baseline and at the end of the intervention period. Youth with diagnosed pathologies (e.g., autism, cerebral palsy, Down Syndrome), health-related concerns (e.g., obesity), or young athletes were excluded. Studies could be randomized controlled trials (RCT) or non-randomized (i.e., quasi-experimental and pre-post design). Community-based interventions, unpublished thesis/dissertations and research studies not published in English were excluded.

Information sources

A systematic search was conducted in December 2020 using three main electronic databases (Web of Science, SPORT Discus and PubMed). A grey literature search of Google Scholar was also conducted to minimize publication bias (Haddaway et al., 2015). Journal articles published in English until the 31th December of 2020 were considered for review.

Search strategy

The specific electronic search for each database and terms included are shown in supplementary materials. PICOS approach was used for framing the research question and the evidence search (Klinker et al., 2015).

Selection process

First, the primary investigator (EVG) screened all titles and abstracts for obvious irrelevance and 10% of these titles and abstracts were also checked by another author (YBR). The 10% screening figure is a recognized validation and agreement threshold for systematic reviews (If et al., 2015). Second, the full text of eligible studies was then located and reviewed by two authors (EVG and YBR). Discrepancies were resolved by consensus between the authors. When there was no consensus, a third author (ADF) acted as mediator. Duplicates, nonintervention studies, non-English language, and studies without analysis of our primary outcomes or target population were eliminated.

Data collection process and data items

Data extraction was independently performed by two researchers (EVG and YBR); discrepancies were resolved by agreement between the two authors. Study data were extracted by EVG.

Study risk of bias assessment

We assessed quality by two different tools: (1) quality assessment of controlled intervention studies (i.e., RCTs and non-randomized studies) and (2) quality assessment tool for before–after (pre–post) studies with no control group (non-randomized studies) (Heart & Lung, 2016). These instruments were created to evaluate the internal validity of a trial, the extent to which the reported effects can strictly be attributed to the intervention applied, and the potential flaws in methodology or implementation. Each tool contained specific questions to assess bias, confounders, power, and strength of association between intervention and outcomes. The answer to each question could be “yes,” “no,” “cannot determine,” “not reported,” or “not applicable”. A numeric scoring system was not used. The evaluator had to consider the potential risk of bias in the study design for each “no” answer selected. Overall quality ratings were scored as “good” (low risk of bias, valid results), “fair” (some risk of bias, does not invalidate results), or “poor” (significant risk for bias, may invalidate results). Critical appraisal involves considering the risk of potential for allocation bias, measurement bias, or confounding (the mixture of exposures that one cannot tease out from each other). Examples of confounding include co-interventions, differences at baseline in patient characteristics, etc. If a study had a “fatal flaw” then the risk of bias was significant and the study was of poor quality (i.e., high dropout rates, high differential dropout rates, intention to treat analysis, or inappropriate statistical analyses). Thus, a study was considered "poor" when it included at least one fatal flaw, "fair" when it did not include any fatal flaw but included some limitation or confounding factor. Finally, “good” studies were those that did not include any fatal flaws or limitations in the study design. All studies were independently screened by one author (EVG) and subsequently 50% of the studies (n =9) were double checked for accuracy by one additional reviewer (YBR).

Effect measures

Effect size was expressed as Hedges’ g to correct for possible small sample bias (Higgins, 2008).

Synthesis methods

All analyses were carried out with the STATA software (v16.1; StataCorp, College Station, TX, USA) and conducted using the random-effects inverse-variance model with the Hartung-Knapp-Sidik-Jonkman adjustment according to muscular tests used (muscular strength and power or local muscular endurance). Changes in outcomes for studies were calculated by subtracting change differences between the exercise and control groups (RCT or non-randomized studies), using the pooled standard deviation (SD) of change in both groups. Regarding pre and post-test intervention, mean differences (baseline vs. post-intervention) and mean standard errors were pooled for each outcome. If change scores SD were not available, they were calculated from 95% confidence intervals (CI) for either change outcome or exercise training effect differences as well as pre-SD and post-SD values (Follmann et al., 1992). However, we also determined mean differences (MD) in each muscular test. It is important to clarify the following aspects relating to our statistical analyses: (1) meta-analyses were only performed for outcomes that were included in three or more studies; (2) when different cohorts, interventions or sexes were included in studies, their data were analyzed as independent samples; and (3) when two or more tests for measuring the same variable were included in a study, we calculated the average Hedge's g. Heterogeneity across studies was calculated using the inconsistency index (I^2), derived from the Cochran Q statistic (Higgins et al., 2003). Larger values for I^2 suggest a larger degree of inconsistency. Small-study effects and publication biases were examined using the Doi plot and Luis Furuya-Kanamori (LFK) index. Both test have been shown to be superior to the traditional funnel plot and Egger's regression intercept test (Furuya-Kanamori et al., 2018). No asymmetry, minor asymmetry or major asymmetry was considered with values of –1, between –1 and –2, and >–2, respectively (Furuya-Kanamori et al., 2018).

Subgroup analysis was conducted according to design of the study (i.e., RCT or non-randomized design), frequency of sessions per week (<3 or ≥3 sessions per week) (Bull et al., 2020), length of the intervention (≤8 or >8 weeks), and duration of the session (<30 min or ≥30 min per session).

Results

Study selection

The PRISMA 2020 flow diagram detailing the procedure can be found in **Figure 1**. In the first stage of the search strategy, a total of (n = 1052) articles were identified. In the second stage, following the removal of duplicates (n = 157), a total of (n = 987) articles were screened by title/abstract. Then, 929 potentially relevant articles were excluded with reasons.

In the third stage, 58 full-text articles were reviewed in depth and (n = 41) studies were excluded with reasons (details summarized in Figure 1). Finally, a total of 17 studies based on PA interventions met the inclusion and exclusion criteria and were included in the final analysis.

Study characteristics

The characteristics of the 17 included studies are presented in **Table 1**. The included studies were conducted in different continents including “the Americas” (Annesi et al., 2005; Faigenbaum et al., 2013, 2015; Faigenbaum, Myer, Farrell, et al., 2014; Siegel et al., 1989), Europe (Alves et al., 2016; Arabatzi, 2018; Engel et al., 2019a, 2019b; Grainger et al., 2020; Granacher, Goesele, et al., 2011; Granacher, Muehlbauer, et al., 2011; Larsen et al., 2016; Lucertini et al., 2013; Marta et al., 2019; Viciana et al., 2013), and Asia (Qi et al., 2019; Sadres et al., 2001). The included studies involved a total of 1653 participants (n =1264 “exercise group” participants and 28% girls), ranging from a sample size of 32 (Granacher, Goesele, et al., 2011; Granacher, Muehlbauer, et al., 2011) to 570 (Annesi et al., 2005) participants. Regarding the study design, most of the studies (n=16) were experimental (i.e., RCT) and one report was a non-randomized study (Annesi et al., 2005). Finally, 6 studies took place in public schools (Alves et al., 2016; Annesi et al., 2005; Faigenbaum et al., 2013, 2015; Faigenbaum, Myer, Cscs, et al., 2014; Marta et al., 2019) whereas the specific type of school was not described in other reports.

Analysis of the MF Intervention and its effects

MF Intervention

All interventions focused on improving MF whereby the main purpose was to promote PA in the school environment with the primary outcome of increasing objectively measured MF. Interventions were categorized following guidelines from Cox et al. (Cox et al., 2020). Most MF interventions included combined activities that targeted the development of muscular strength and muscular power (n=12). Other interventions were carried out using traditional MF methods, i.e., free weights and weight machines (n=2)(Granacher, Goesele, et al., 2011; Viciana et al., 2013), plyometrics (n=1)(Arabatzi, 2018), body weight training (n=1) (Engel et al., 2019a), and focused on lower body activities, i.e., balance training (n=1)(Granacher, Muehlbauer, et al., 2011). Regarding the duration of the intervention periods, 6 of 17 studies lasted eight weeks with a study duration range of 4 weeks (Arabatzi, 2018; Engel et al., 2019a; Grainger et al., 2020; Granacher, Muehlbauer, et al., 2011) to 10 months (Larsen et al., 2016). Regarding school context, most of studies were carried out during physical education (PE) classes (10/17). Concerning frequency (d/wks) and session duration (min), most studies included two sessions per week (12/17), whereas the session duration varied across studies with a range between 15- and 90-min. MF training intensity across the interventions varied due to different methods used to prescribe the training load, e.g., percent of 1 repetition maximum (Granacher, Goesele, et al., 2011; Qi et al., 2019; Sadres et al., 2001), and ratings of perceived exertion (Engel et al., 2019a). In 6 studies the training intensity was not reported. Finally, the training volume varied across interventions due to differences in the number of exercises, sets, repetitions and load throughout the study period.

Results of individual studies

Regarding the effect of the interventions on MF outcomes, there were significant positive results in fifteen out of seventeen of the studies (88%). In the study by Granacher et al., (Granacher, Muehlbauer, et al., 2011), the effects of the intervention on grip strength were inconclusive with the exception of right grip strength in which a decrease in strength was observed in the fundamental movement skills group. In addition, Grainger et al., (Grainger et al., 2020) found non-significant positive results with slight increases in countermovement jump height in the EG following MF training. Methods of assessing local muscular endurance included the sit-up and push-up tests (Annesi et al., 2005; Engel et al., 2019a; Faigenbaum et al., 2015; Faigenbaum, Myer, Cscs, et al., 2014; Lucertini et al., 2013; Siegel et al., 1989; Viciana et al., 2013). With respect to muscular strength and muscular power, most of studies included lower limbs assessments including the standing long jump, single-leg hop tests, countermovement jump, vertical jump, drop jump and knee extension-flexion or upper body assessments including the 1-kg and 3-kg medicine ball toss, hand-grip, pinch-strength, biceps curl test, cable flexion, cable extension, flexed arm hang and pull-ups.

Risk of bias in studies

In summary, six studies were rated as “good”, two as “fair”, and nine as “poor” in their quality assessment (supplementary materials). We assessed sixteen studies with this tool. Most studies (8/16) identified as controlled studies included a “fatal flaw” resulting in a “poor” rating, whereas six studies (35%) did not reported any “fatal flaw” (Faigenbaum et al., 2013, 2015; Faigenbaum, Myer, Farrell, et al., 2014; Granacher, Goesele, et al., 2011; Granacher, Muehlbauer, et al., 2011; Viciana et al., 2013). Only four studies described the randomization process (Alves et al., 2016; Grainger et al., 2020; Larsen et al., 2016; Marta et al., 2019) identifying the randomization sequence. The “blinding/shielding” components (item n.4) was inapplicable because it is virtually impossible to blind participants receiving an intervention in the school context, in this case an MF intervention. However, item n.5

was considered, since this blinding criterion ("*Were the people blinded to the participant's group assignment?*") could have been met in the exercise intervention studies. Most of the controlled intervention studies (12/16) had similar groups at baseline on important characteristics that could affect the outcome of the study. The overall dropout rates from all the studies were less than 20%, as well as there were no substantial differences in the dropout rate (15% or higher) between arms, i.e., intervention and control groups. Adherence to the intervention program was high (>75%) in most groups (13/16), where three studies did not reported attendance data (Marta et al., 2019; Qi et al., 2019; Siegel et al., 1989). The application of other interventions was not described in any cases. Furthermore, although none of the seventeen studies reported an appropriately sized sample necessary for detecting effects with 80% power, ten studies (58%) considered clustering effects in their statistical analysis, reducing the bias associated with a low sample of participants. Finally, in all studies, all randomized participants were analyzed in the group to which they were originally assigned (per protocol analysis).

Concerning the quality assessment for before–after studies (Pre–Post) with no control group, we assessed only one study with this tool (i.e., non-random studies without a control group). The study of Annesi et al., (Annesi et al., 2005) included some "fatal flaws", resulting in a "poor" rating.

Results of synthesis

Local Muscular Endurance. Compared with the control group, exercise interventions were associated with significant moderate increases in local muscular endurance (Hedge's g=0.65 95% CI, 0.13 to 1.17, p=0.020; I^2=85.0%) (**Figure 2**). Cochran's Q statistic for statistical heterogeneity was 53.40 (p<0.001). Concerning to test used, exercise interventions favor an increase of number of repetitions in push-ups of 1.37 (95% CI 0.91 to 1.83, p=0.001; Q=3.97; I^2=0%). However, significant effects disappeared when we used only RCTs (Hedge's g=0.29 95% CI, -0.12 to 0.70, p=0.120; I^2=22.0%) or combined activities (Hedge's g=0.66 95% CI, -0.06 to 1.38, p=0.065; I^2=88.4%).

Subgroup analysis shows that interventions with ≥3 sessions per week (Hedge's g=0.98 95% CI, 0.04 to 1.93, p=0.033; Q=28.86; I^2=86.1%) favored larger increases of local muscular endurance compared to interventions with <3 sessions per week (Hedge's g=0.27 95% CI, -0.22 to 0.76, p=0.001; Q=4.29; I^2=30.0%), without differences between them (p=0.077). According to length of the intervention and duration of sessions per week, significant effects disappeared when we used only interventions ≤8 (Hedge's g=0.45 95% CI, -0.03 to 0.93, p=0.133; Q=0.74; I^2=0%) or >8 weeks (Hedge's g=0.65 95% CI, -0.16 to 1.52, p=0.095;

Q=53.40; I^2=85.0%) and sessions <30 (Hedge's g=0.45 95% CI, -0.03 to 0.93, p=0.133; Q=0.74; I^2=0%) or ≥30 minutes (Hedge's g=0.65 95% CI, -0.16 to 1.52, p=0.095; Q=53.40; I^2=85.0%).

Muscular Strength and Muscular Power. Exercise interventions favored increases in muscular strength (Hedge's g=0.33 95% CI, 0.16 to 0.51, p=0.001; I^2=59.3%) (**Figure 3**). Cochran's Q statistic for statistical heterogeneity was 39.33 (p=0.001). Subgroup analysis shows that combined activities (Hedge's g=0.26 95% CI, 0.15 to 0.39, p=0.001; Q=7.15; I^2=0%) led similar increases than overall results, but without heterogeneity. Regarding the test used, no significant effects were observed (Counter movement jump, MD=0.03 m 95% CI, -0.22 to 0.28, p=0.768; Q=23.4; I^2=70.2%; Handgrip, MD=0.36 kg 95% CI, -0.41 to 1.13, p=0.306; Q=7.4; I^2=5.0%; Knee extension, MD=-0.01 kg 95% CI, -4.0 to 4.02, p=0.991; Q=9.3; I^2=78.6%; Knee flexion, MD=0.59 kg 95% CI, -0.99 to 2.17, p=0.251; Q=0.1; I^2=0%; Standing-long jump, MD=0.22 cm 95% CI, -0.22 to 0.66, p=0.285; Q=20.95; I^2=61.8%). Concerning the design of the study, RCTs led to slightly higher increases (Hedge's g=0.37 95% CI, 0.16 to 0.57, p=0.002; Q=36.8; I^2=62.0%).
Subgroup analysis shows that interventions with ≥3 sessions per week (Hedge's g=0.54 95% CI, 0.03 to 1.05, p=0.041; Q=28.56; I^2=78.9%) favored higher increases compared to interventions with <3 sessions per week (Hedge's g=0.23 95% CI, 0.12 to 0.34, p=0.002; Q=7.24; I^2=0%), without significant differences between groups (p=0.060). According to length of the intervention and duration of sessions per week, effects remained significant when we used only interventions ≤8 (Hedge's g=0.39 95% CI, 0.09 to 0.69, p=0.016; Q=32.92; I^2=69.6%) or >8 weeks (Hedge's g=0.27 95% CI, 0.07 to 0.46, p=0.018; Q=6.19; I^2=19.3%) and or ≥30 minutes (Hedge's g=0.27 95% CI, 0.16 to 0.44, p=0.004; Q=25.19; I^2=48.4%), but not in sessions <30 minutes (Hedge's g=0.63 95% CI, -0.57 to 1.84, p=0.152; Q=8.12; I^2=75.4%)

3.6. Reporting biases and sensitivity analysis
Minor and major asymmetry suggestive of small-study effects were observed for local muscular endurance (LFK index=1.01) and muscular strength and muscular power (LFK index=2.03), respectively (supplementary materials).
Regarding sensitivity analyses, with each study deleted from the model once, nonoverlapping 95% CI were observed across all deletions for muscular endurance (ranging from 0.46 [95% CI, 0.11 to 0.81] (Annesi et al., 2005) to 0.76 [95% CI, 0.28 to

1.25])(Lucertini et al., 2013) and muscular strength (ranging from 0.26 95% CI, 0.17 to 0.36 (Engel et al., 2019a) to 0.30 [95% CI, 0.20 to 0.40]) (Lucertini et al., 2013).

Discussion

Summary of Main Results

The current study found that school-based exercise interventions were associated with significant small-to-moderate increases in MF with larger effects observed in interventions with at least three sessions per week. However, the small-to-moderate findings of this meta-analysis should be interpreted with caution and considered considering the high heterogeneity and a lack of specificity regarding the desired MF outcome in the studies. However, the findings should be interpreted with caution while keeping in mind the large heterogeneity among results, the low quality of the trials and publication bias in muscular strength and muscular power.

Effects on local muscular endurance, muscular strength and muscular power

In this meta-analysis, school-based exercise interventions were associated with small-to-moderate increases in local muscular endurance, muscular strength and muscular power in children. However, our meta-analysis found no clear significant differences in training-induced MF performance when the effect of the different interventions on MF was compared. Of note, Cox et al. (Cox et al., 2020) showed that plyometric activities demonstrated a statistically significant, homogeneous effect on MF outcomes in adolescents' boys. Plyometric training has been found enhance muscle strength, muscular power and bone strength in youth (Ramirez-Campillo et al., 2020). We only included one study that exclusively used plyometric training in children and therefore our discussion of potential benefits is limited (Arabatzi, 2018). Most studies used combined MF activities that incorporate some type of plyometric training into the intervention. For example, three of the studies (Faigenbaum et al., 2013, 2015; Faigenbaum, Myer, Cscs, et al., 2014) used integrative neuromuscular training protocols which incorporated a variety of strength and conditioning exercises into every lesson with the purpose of enhancing both health- and skill-related components of physical fitness (Myer et al., 2011). These interventions typically included dynamic movements using medicine balls, plyometric exercises such as jumps and hops as well as different body weight strength building activities. In our report most of the school-based exercise interventions included combined activities (n=12) highlighting this integrative approach as a promising protocol. As such, integrative neuromuscular training that is developmentally appropriate for children may be needed to prevent the accumulation of risk factors, functional limitations, and interrelated processes that drive physical inactivity in modern day youth (Myer et al., 2011). Notably, integrative neuromuscular training does not involve expensive exercise equipment or heavy external loads.

Subgroup Analysis

The literature suggests that MF interventions should include 8-12 weeks in order to be effective during childhood and adolescence (Stricker et al., 2020). In this meta-analysis, meta-regression analyses revealed nonsignificant moderation of duration of interventions and sessions (min) for both local muscular endurance, muscular strength and muscular power. However, these analyses revealed significant effects of weekly training frequency (i.e., number of sessions) on the effect size estimate. The present meta-analysis included a total of 13 studies lasting at least eight weeks and all had a training frequency of at least 2 sessions per week. Previous research has indicated that 2–3 sessions per week on non-consecutive days is most appropriate in order to develop MF levels in youth (Lloyd et al., 2014). Also, strength gains occurred with different types of resistance training for a minimum duration of 8 weeks with a frequency of 2 to 3 times a week, a training dose that was met in all the interventions used in this meta-analysis (Stricker et al., 2020). Notwithstanding the influence of training intensity and training volume on MF outcomes, it seems that in the case of muscular strength and muscular power development, a greater training frequency (e.g., 3 vs 2) may be associated with a greater increase in MF. In support of these findings, the WHO recommends muscle and bone strengthening exercises at least 3 days/week (Bull et al., 2020). In order to determine the importance of the training frequency, we carried out an additional sub-group analysis and found that interventions with ≥3 sessions per week favored larger increases in local muscular endurance and muscular strength and power. Notably, the weekly resistance training frequency in an educational context will likely be determined by the educational curriculum of the state or region in which the physical education intervention takes place.

Concerning fitness tests used in our meta-analysis, exercise interventions resulted in an increase in the number of push-up repetitions by 1.37, whereas no significant effects were observed between the different tests used to evaluate muscular strength and muscular power. Others (Ruiz et al., 2011) noted that muscular strength could be considered a marker of health already at childhood and adolescence, as well as health indicators of future cardiovascular health. The handgrip strength test and the standing long jump test are valid and reliable measures that can be used to assess MF, and these tests are feasible in school setting.

There are limitations to our report that should be considered when interpreting the results. Regarding age, in the present meta-analysis we included studies involving children (girls and boys) <13 years old (i.e., mainly primary school age). This age criterion is recommended by the International Consensus on Youth Resistance Training (Lloyd et al., 2014). However, based on our knowledge, since late childhood and early adolescence cannot be defined by fixed chronological boundaries, childhood can be defined as the first birthday to the onset of adolescence (which requires the identification of the onset of sexual maturation). Adolescence is a difficult period to define, and some suggest a range of 10-22 years in boys. WHO states adolescence begins with the onset of normal puberty and ends with adult identity, roughly 10-19 years of age. However, significant interindividual variance exists for the level (magnitude of change), timing (onset of change), and tempo (rate of change) of biological maturation. The relative mismatch and wide variation in biological maturation between children of the same chronological age emphasizes the limitations in using chronological age as a determinant.

Conclusion

Given the small number of trials, the heterogeneity of results, and moderate-to-high risk of bias, caution is warranted regarding the strength of the existing evidence base. Nevertheless, our findings indicate that school interventions based on muscle and bone strengthening exercises performed at least 3 days per week may serve to support the development of MF in girls and boys and, therefore, enhance their health and well-being.

Disclosure statement

No potential conflict of interest was reported by the author(s).

SUPPLEMENTARY MATERIAL

Supplementary data have been deposited in the institutional research repository of the University of Granada (ROAR:437). re3data.org: Digibug; editing status 2021-09-06; re3data.org - Registry of Research Data Repositories. http://doi.org/10.17616/R39F4K. To access these data: http://hdl.handle.net/10481/71015.

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Figure 1. PRISMA 2020 flow diagram for systematic reviews which included searches of databases.

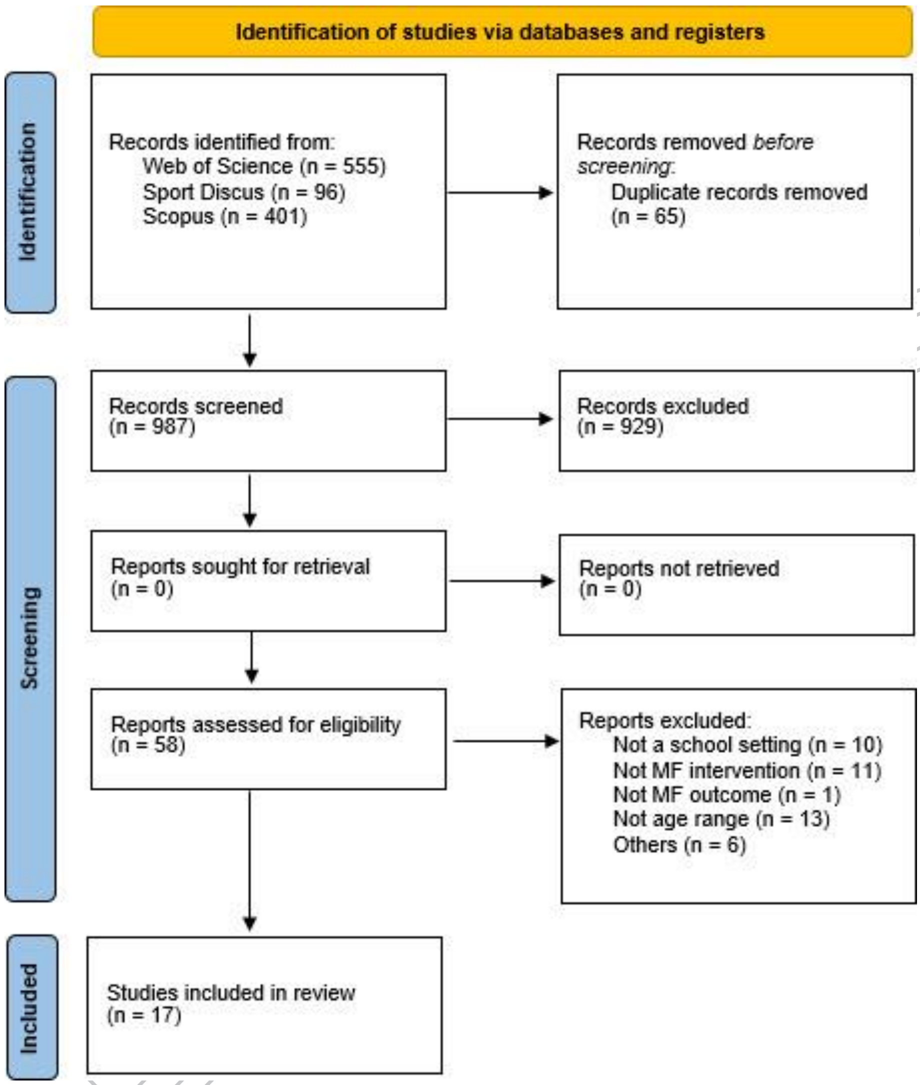

Figure 2. Forest plot showing estimates of the size of change in local muscular endurance after a school-based PA intervention.

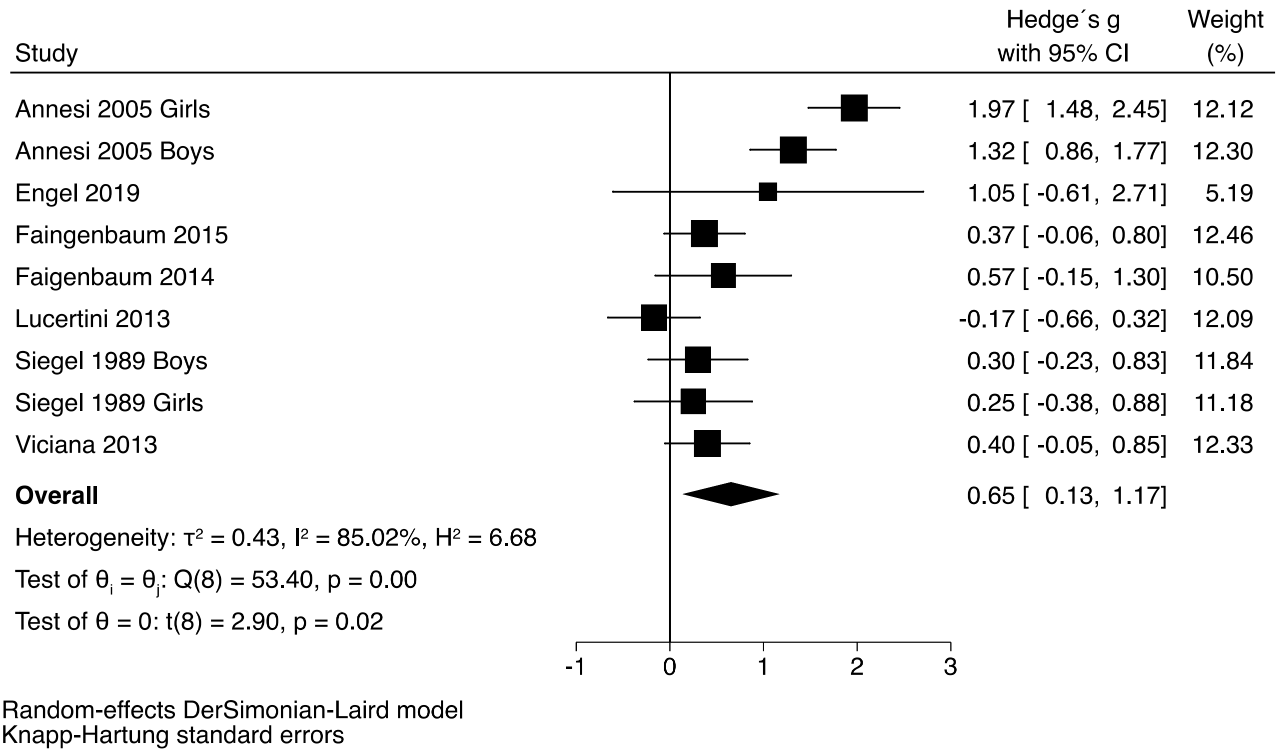

Figure 3. Forest plot showing estimates of the size of change in muscular strength and power after a school-based PA intervention.

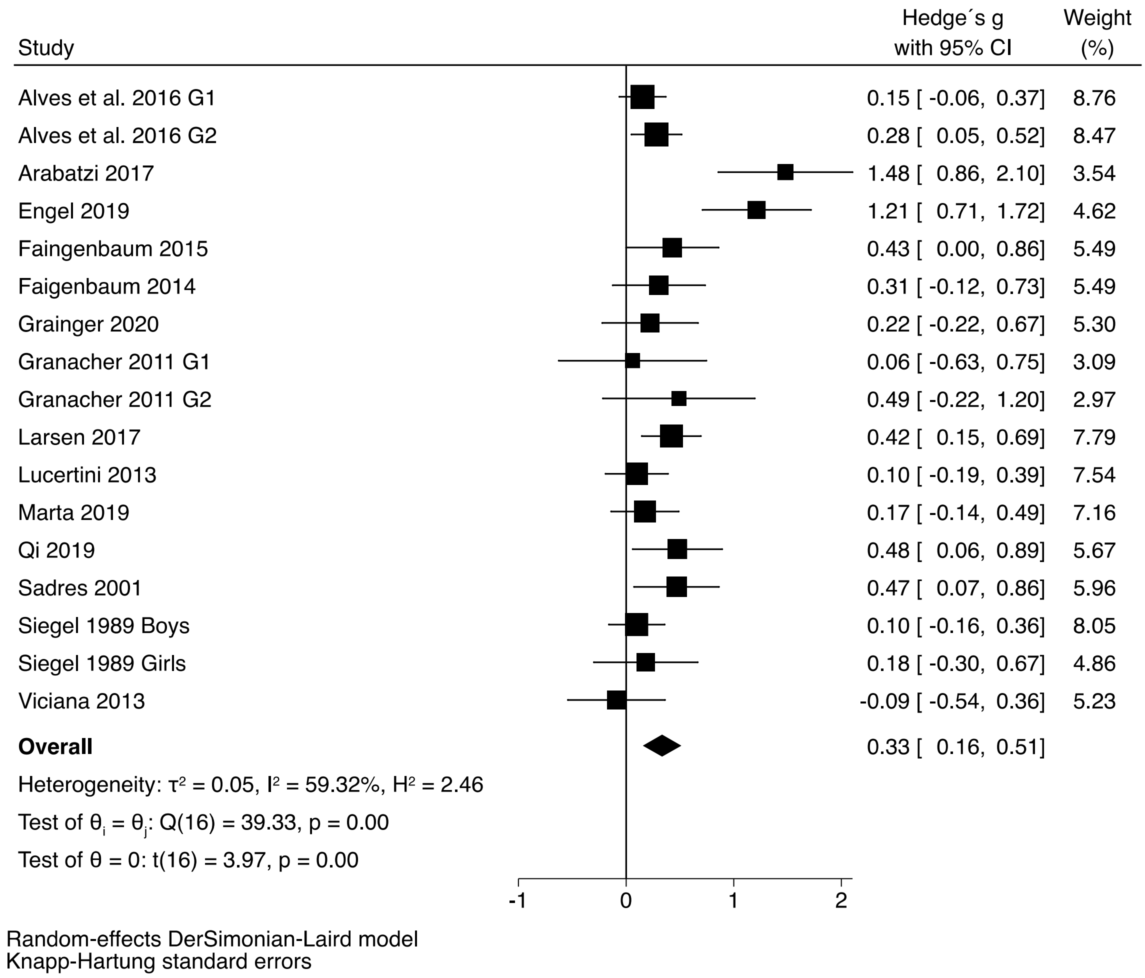

Table 1. Characteristics of MF studies included in this systematic review *(n=17)*.

Author and country	**Sample and age (years)**	**Intervention study design**	**School / (n)**	**Study Length (wks/months)/school space**	**MF Intervention**	**Frequency (D/WK/ duration)**	**Intensity**	**Volume (Set x REPS)**	**MF outcome measures**	**Results from MF outcomes**
Alves et al. (2016) Portugal	128 healthy prepubescent children (aged 10-12 years)	Experimental (RCT) pre-post assessment with two EG and a CG	Public /(n =1)	8 wks/in addition to the physical education classes	***Concurrent Training*** Intrasession concurrent strength before aerobic training group (GSA), intrasession concurrent aerobic before strength training group (GAS). Exercises: 1-kg ball throw, 3-kg ball throw, SLJ and CMJ.	2 x ~45 (min NR)	Maximal dynamic strength	1-kg ball throw (from 2 to 3 sets/ 8 REPS) 3-kg ball throw (from 2 to 3 sets/ 6-8 REPS) SLJ (from 2 to 4 sets/ 4 REPS) CMJ (from 1 to 3 sets/ 5 REPS)	Muscle/bone strengthening (1-kg and 3-kg medicine ball throw, standing long jump, counter movement jump)	Training-induced differences were found in the experimental groups. All programs were effective, but GSA produced better results than GAS for muscle strength variables (p<0.001)
Annesi et al. (2005) USA	570 children aged 5-12 years	Quasi-experimental design with pre-post assessment at 14 schools (EG)	Public /(n =14)	12 wks/ YMCA school care sites (school gymnasium or a multipurpose room)	***Combined Activities*** Strengthen major muscle groups Exercises: 3-6 exercises	3 x 45 min	NR	1-3 sets of 10–12 reps/set	Muscle /bone strengthening (3-s cadence push-ups test)	All Age x Sex subsamples demonstrated significant increases in strength (p<0.001)
Arabatzi et al. (2018) Greece	50 children aged 9.30± 0.5 years	Experimental (RCT) pre-post assessment with EG and CG	NR / (n= 1)	4 wks/PE classes	***Plyometric Activities*** Trampoline plyometric training Exercises: double-leg jumps on a mini trampoline	3 x 45 min	NR	10 sets of 8 reps during the first 2 weeks, 10 sets of 10 jumps during the third week and 10	Muscle/bone strengthening (CMJs and three DJs)	Significant main effect of “time” and “group X time” interaction effect (P=0.002) was observe

								sets of 12 jumps during the fourth week		d for CMJ
Engel et al. (2019) Germany	35 children aged 11.7± 0.3 years	Experimental (RCT, controlled double-arm clinical study) pre-post assessment with EG and CG	NR / (n=1)	4 wks/ within regular school classes	***Body Weight Activities*** Micro-session of Functional HIIT Exercises: Multiple-joint exercises	4 x 6 min	"all-out" effort at high velocities targeting >17 on the 6−20 Borg scale and with the children's own bodyweight	High repetitions	Muscle/bone strengthening (German motor ability test: SLJ, Lateral jumping, Sit-ups and Push-ups)	Performance in lateral jumping and sit-ups were greater after 4 weeks Functional HIIT compared to the control group (p=0,000; global effect of Time × Group)
Faigenbaum et al. (2015) USA	41 children aged 9-10 years	Experimental (Cluster RCT) pre-post assessment with EG and CG	Public / (n=1)	8 wks/during the first 15 minutes of each regularly scheduled 45-minute PE classes	***Combined Activities*** Fundamental integrative training (FIT) included a series of progressive exercises using body weight and medicine balls (1–2 kg), fitness ropes, equalizer bars, BOSU balance trainers, fitness spots, dome cones, punch balloons,	2 x 15 min	low to high intensity bouts of strength	30 seconds during weeks 1–4 and for 45 seconds during weeks 5–8	Muscle/bone strengthening (SLJ, SLH, Sit-ups)	A significant interaction of group and time was observed after the 8-week intervention for the push-up and single-leg hop (all=<0.05). Pre-post percent changes after FIT were significantly greater for the push-up and single-

					and spooners Exercises: Circuit of 6–7 exercise				leg hop (all= <0.05)
Faigenbaum et al. (2013) USA	39 children aged 7 years old	Experimental (Cluster RCT, randomized controlled trial) pre-post and follow-up assessment with EG and CG	Public / (n=1)	8 wks /during the first 15 minutes of each regularly scheduled 43-minute PE classes	***Combined Activities*** Integrative Neuromuscular Training (INT) program Primary exercises that focused on enhancing muscular strength and power, and secondary exercises that aimed at improving fundamental movement skills Exercises: Primary and secondary strength and power exercises	2 x 15 min	low to high intensity bouts of strength	2 sets on all exercises, and the repetitions (7–10) or set duration (10–30 seconds) was gradually progressed over the 8-week training period	Muscle/bone strengthening (curl-up, standing long jump and single-leg hop tests)	The exercise group made greater gains (relative to control) in the maximum number o curl-ups at a post-training measure (p<0.05) and a significant interaction of time by group were shown in the curl-up, and single-leg hop test
Faigenbaum et al. (2014) USA	40 children aged 7 years old	Experimental (Cluster RCT) pre-post assessment with EG and CG	Public / (n=1)	8 wks /during the first 15 minutes of each regularly scheduled 43-minute PE classes	***Combined Activities*** Same INT (Faigenbaum et al. (2013)	2 x 15 min	low to high intensity bouts of strength	2 sets on all exercises, and the repetitions (7–10) or set duration (10–30 seconds) was gradually progressed	Muscle/bone strengthening (curl-up, standing long jump and single-leg hop tests)	Intervention effects were found in the girls for enhanced INT-induced gains in performance relative to the control

								over the 8-week training period		group on the curl-up, long jump, single-legged hop (P=0.05) after controlling for baseline
Grainger et al. (2020) UK	72 children aged 10-11 year	Experimental (RCT, randomized controlled trial) pre-post assessment with EG and CG	NR / (n= 3)	4 wks/ in addition to the usual PE lesson	***Combined Activities*** Integrated Strength and Fundamental Movement Skill Training with two groups: (FMS) or FMS and strength (FMS+) Exercises: Five activities with several FMS and RT exercises	2 x 50-60 min	NR	Different sets and REPS.	Muscle/bone strengthening (CMJ and Hand-grip)	The effects of the interventions on grip strength were clearly inconclusive with the exception of right grip strength where a potential decrease in strength was observed in the FMS group (p = 0.36).
Granacher et al. (2011) Switzerland	32 children aged 8-12 years	Experimental (controlled study) pre-post assessment with EG and CG	NR / (n= 2)	10 wks/PE classes	***Traditional Methods*** High-intensity strength training (HIS) with weight machines Exercises: leg-press, knee extension /flexion, seated calf-raise, weight-machine for hip	2 x 90 min	70–80 % of the 1RM	3 sets of 10-2 REPS	Muscle/bone strengthening (Isokinetic peak force of the knee extensors and flexors with a isokinetic dynamometer and CMJ)	Peak torque of the knee extensors and flexors were significantly improved at movement velocities of 60 °/ s and 180 °/s following 10 weeks of HIS; and strength

					abduction/adduction and core exercises.					gains in knee extensors and flexors did not result in significant improvements in CMJ jumping height
Granacher et al. (2011) Switzerland	32 children aged 6-7 years	Experimental (controlled trial) pre-post and follow-up assessment with EG and CG	NR / (n=2)	4 wks/ during regular PE classes	***Lower Limb Activities*** Balance training Exercises: exercises with unstable training devices (soft mats, ankle disks, balance boards, air cushions)	3 x 60 min	Exercise intensity was progressively increased by reducing the base of support, by using dynamic arm movements to perturb the center of gravity, and by reducing the sensory input	4 sets of each exercise lasting 20 seconds with a 40-second rest in between.	Muscle/bone strengthening (CMJ)	Slight increases were found in CMJ height in the EG from pre, to post, to follow-up testing, but no significant Group x Test interaction was found for CMJ height ($p>0.05$)
Larsen et al. (2016) Denmark	83 children aged 8-10 years	(RCT) pre-post assessment with EG and CG	NR / (n=4)	10 months/ at the schools in the afternoon	***Combined Activities*** Circuit strength training group (CST) with plyometric and strength exercises Exercise: jumps, sit-ups, push-ups	3 x 40 min	all-out exercise	30 s all-out exercise periods (6-10 stations) interspersed by 45 s rest periods	Muscle/bone strengthening (SLJ)	Higher change scores in jump length vs CON ($p<0.05$) was observed

					and other dynamic exercises as well as static strength training using upper and lower body, as well as the core					
Lucertini et al. (2013) Italy	101 children aged 9.8 years (mean age)	Experimental (RCT) pre-post assessment with two EG and one CG	NR / (n= 3)	6 moths/ PE classes	***Combined Activities*** GE1 performed Strength training based on machines, GE2 performed Strength training with traditional and non-traditional devices Exercises: GE1 performed a specifically designed resistance devices (the ‘‘Kid's System'', Panatta Sport, Apiro, MC, Italy), whereas GE2 trained with a traditional or non-conventional device (e.g., light dumbbells, elastic bands,	2 x 60 min	NR (but same training load for both experimental groups)	NR	Muscle/bone strengthening (Pinch-strength and hand-grip strength tests), abdomen (sit-up) endurance test) and lower limbs (swinging counter movement jump [CMJ] power test)	Both experimental groups and the control group significantly increased hanggrip (in both dominant and non-dominant hand) (p<0.05). Higher scores in the CMJ test at follow-up, in both the experimental groups than the control group (p<0.01). EG2 scored significantly better than CG in both dominant (P<0.05) and non-dominant

					plastic water bottles, etc.).					(P<0.01) push-up tests, while EG1 scored significantly better than group EG2 (p<0.05) and CG (p<0.01) in the abdomen test
Marta et al. (2019) Portugal	57 boys aged 10-11 years	Experimental (RCT) pre-post assessment with two EG and a CG	Public / (n=1)	8 wks/ school-based training programs	***Combined Activities*** GE1 performed Resistance Training (RT) and GE2 carried out Suspension Training (ST). Exercises: 7 exercises for RT and ST groups respectively. RT program composed of 1- and 3-kg medicine ball throws, jumps onto a box (from 0.3-to-0.5-m-tall), plyometric jumps above 0.3 to 0.5 m tall hurdles, and sets	2 x ~45 min	NR	Exercises were performed increasing sets and decreasing REPS	Muscle/bone strengthening (CMJ, SLJ, Medicine Ball Throwing)	Changes from preintervention to postintervention for the 1-kg ball throw were 5.94% and 5.82%, for the ST and RT, respectively, and 8.82% and 8.14% in the 3-kg ball throw for the ST and RT, respectively

					of 30-to-40-m-speed runs. The ST group included chest press, push-up, triceps press, triceps extension, squat, lunge, and sprinter start exercises					
Qi et al. (2019) China	46 boys aged 8-12 years	Experimental (RCT) pre-post and follow-up assessment with EG and CG	NR / (n= 1)	12 wks/ PE sessions	***Combined activities*** Resistance and plyometric training exercises Exercises: Back squat lunges, Abdomen upward jump, back squat, single - leg hop, barbell biceps curl, frog jump, push up, 30-m sprint running	2 x 60 min	70%-80% of 1 repetition maximum	From 2 to 3 sets x different REPS range (10-30)	Muscle/bone strengthening (6-repetition maximum (RM) in the biceps curl test, assessed 1 week before at the 1-RM test, VJ)	EG showed a significantly greater increase on biceps curl (p= 0.005) and the standing long jump (p= 0.015) in comparison with the CG
Sadres et al. (2001) Israel	60 boys aged 9-10 years	Experimental (RCT) pre-post assessment with EG and CG	NR / (n= 2)	9 months/ PE sessions	***Combined activities*** Resistance and weightlifting exercises using free weights and different activities Exercises: A total of 3-6 exercises such as;	2 x 50-55 min	30-70% of 1RM (first school year) and 50-70% of 1RM (second school year)	A total of 150 repetitions (1-4 sets/exercises with 5-30 REPS)	Muscle/bone strengthening One-repetition maximum (1RM), Concentric strength of the knee flexors	The experimental group was significantly stronger in all strength measures throughout the study period (p<0.05). The significant

					clean pulls, jerk, clean, squats, dead lift, snatch and snatch pulls; using free weights and activities such as running, jumping, and throwing, using different means such as medicine ball (1-3 kg), skipping ropes, and others				and extensors was measured using the Shnell M3 Multi Muscle Machine	time-group interaction found in all strength measures reflects the greater strength increase observed in the EG compared with control group ($p<0.05$)
Siegel et al. (1989) USA	96 children aged (mean age=8.6±0.5)	Experimental (RCT) pre-post assessment with EG and CG	NR / (n=2)	12 weeks / recess (free play period)	***Combined activities*** Three formats of training programs: 1) obstacle course; 2) a choreographed weight routine and; 3) circuit training. Exercises: 1) upper body self-supported locomotor movements, i.e., wheelbarrow, sealwalk, crabwalk, etc; 2) Routine using	3 x 30 min	NR	Approximately 20 minutes each session (30 seconds of work alternated with 30 seconds of rest, progressing to 45 seconds of work and 15 sec of rest), concentrating on upper body resistance exercise	Muscle/bone strengthening Upper body strength: Cable flex (kg) Cable extension (kg), Handgrip (rt)(kg), Handgrip (lt) (kg), Chin-ups (no.), Flexed arm hang (sec) and Sit-ups (no. in 1 min)	The changes in strength were significantly greater for the EG compared to the CG for the right handgrip (+ 1.5 kg vs. +0.3 kg), for chin-ups (+ 1.0 vs. - 0.2), for the flexed arm hang (6.8 sec vs. - 3.2 sec). All ($p<0.05$)

					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 and; 3) circuit training using various types of accessories as resistance, tennis balls for squeezing, and strips of rubber tire to pull					
Viciana et al. (2013) Spain	75 children aged 10-12 years	Experimental (RCT) pre-post assessment with EG and CG	NR / (n= 1)	8 wks/ PE classes	***Traditional methods*** Traditional RT program with strength stations Exercises: Two circuits of eight stations with different exercise such as throwing from the chest, rowing, going up-down, triceps extension biceps curl up, skipping rope, crunches and bridging	2 x 50 min	Three levels of difficulty in each station (low/ medium/ high resistance)	Exercise lasting 15–35 seconds, with a rest time of 25–45 seconds between stations	Muscle/bone strengthening (SLJ, Sit-ups, flexed arm hang test)	The EG had significantly greater gains in sit-ups (p=0.765) and flexed arm hang test (p=0.842) compared to the CG.

Abbreviation: CG; control group, CMJ; Contramovement jump, CST; Circuit strength training group, DJs: Drop Jump, EG; experimental group, FMS; Fundamental Movement Skill, HIIT: High intensity interval training; HIS; High-intensity strength training, INT; Integrative Neuromuscular Training, PE: Physical Education; RCT; randomized controlled trial REPS; repetitions, RT; resistance training, RM; repetition maximum, NR; non reported, SLJ; Squat long jump; ST; suspension training, WKS; weeks.