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Title: The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis

Running title: The benefits of muscular fitness for youth

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Abstract

Physical fitness during childhood and adolescence has been identified as an important determinant of current and future health status. While research has traditionally focused on the association between cardio-respiratory fitness and health outcomes, the association between muscular fitness (MF) and health status has recently received increased attention. The aim of this systematic review and meta-analysis was to evaluate the potential physiological and psychological benefits associated with MF among children and adolescents. A systematic search of six electronic databases (PubMed, SPORTDiscus, Scopus, Embase, PsycINFO and OVID MEDLINE) was performed on the 20th May, 2013. Cross-sectional, longitudinal and experimental studies that quantitatively examined the association between MF and potential health benefits among children and adolescents were included. The search yielded 110 eligible studies, encompassing six health outcomes (i.e., adiposity, bone health, cardiovascular disease [CVD] and metabolic risk factors, musculoskeletal pain, psychological health and cognitive ability). The percentage of studies reporting statistically significant associations between MF and the outcome of interest was used to determine the strength of the evidence for an association and additional coding was conducted to account for risk of bias. Meta-analyses were also performed to determine the pooled effect size if there were at least three studies providing standardised coefficients. Strong evidence was found for an inverse association between MF and total and central adiposity, and CVD and metabolic risk factors. The pooled effect size for the relationship between MF and adiposity was r = -0.25 (95% CI = -0.41 to -0.08). Strong evidence was also found for a positive association between MF and bone health and self-esteem. The pooled effect size for the relationship between MF and perceived sports competence was r = 0.39 (95% CI = 0.34 to 0.45). The evidence for an association between MF and musculoskeletal pain and cognitive ability was inconsistent/uncertain. Where evidence of an association was found, the associations were generally low-to-moderate. The findings of this review highlight the importance of developing MF during youth for a number of health-related benefits.

1. Background

Physical fitness can be defined as the capacity to perform physical activity and is primarily determined by genetics and training [1, 2]. For most individuals, changes in the frequency, intensity, duration or type of physical activity will produce changes in physical fitness - although the amount of adaptation can vary considerably [3]. The fitness components that have been shown to directly relate to improvements in health are cardio-respiratory fitness (CRF) (also known as cardiovascular fitness, cardio-respiratory endurance and maximal aerobic power), flexibility, muscular strength, local muscular endurance and body composition [4-7]. More recently, the term ‘muscular fitness’ (MF) has been used to represent muscular strength, local muscular endurance and muscular power. Generally defined, muscular strength is the ability to generate force with a muscle or group of muscles; local muscular endurance is the ability to perform repeated contractions with a muscle or group of muscles under sub-maximal load; and muscular power refers to the rate at which muscles perform work [8, 4, 7].

Typically, children exhibit a gradual linear increase in muscular strength and muscular power from three years of age until puberty for boys, and until about 15 years for girls [9, 10]. These changes are closely associated with changes in body size and fundamental movement skill aptitude. After this time, boys show a dramatic acceleration of muscular strength until the age of 17 and beyond, and girls show a pronounced plateauing and regression in late adolescence and beyond [7]. Similarly, during childhood both boys and girls make gradual improvements in local muscular endurance, exhibiting similar relative endurance levels (adjusted for body mass) [7]. Importantly, the literature clearly states that performance of any movement task requires varying degrees of MF, given that all movements of the body engage the muscular system to move the skeleton [7]. Consequently, a stronger, more enduring and more powerful musculoskeletal system will enable children and adolescents to perform bodily movements more efficiently and effectively, and may decrease their susceptibility to sports-related injuries [11].

Recent global physical activity guidelines for youth emphasise participation in high intensity physical activity and include a recommendation to perform ‘muscle and bone strengthening’ physical activities on at least three days per week [12]. Furthermore, supervised and appropriate resistance training activities have been recommended for children and adolescents in a recent international position statement [13]. Despite these guidelines and strong evidence for maintaining high levels of physical fitness, a decline in fitness levels in children and youth has been reported worldwide [14-22]. While much of the focus has been centred on the decline in CRF, a decline in levels of MF has also been observed in young people [23-25, 20]. However, it must be noted that there is no reliable standard assessment battery for the assessment of MF in children and adolescents, making comparisons over time, and between nations and groups challenging [26, 27].

Traditionally, research investigating the link between physical fitness and health outcomes has focused on CRF, clearly demonstrating that it is strongly associated with health [2, 27]. However, several studies among adults examining the benefits of MF have also shown strong links to health [28-30]. These studies have not only demonstrated that MF is directly linked to all-cause mortality, but also that a threshold effect exists whereby no additional reduction in mortality risk is gained by increasing MF beyond a certain level [28-30]. The impetus for promoting adequate levels of MF in children and adolescents is based on the growing body of evidence associating MF with an array of health benefits. The emerging body of evidence has demonstrated that MF is favourably associated with adiposity [31], insulin sensitivity [32], bone health [33], psychological health and academic performance [34, 35]. Importantly, current literature suggests that many of these benefits are independent of CRF, providing a strong rationale for integrating different types of training into youth fitness programs [36] . Recent studies also support the benefits of MF for improving sports performance and for injury prevention in young people [37]. Additionally, levels of MF in childhood have been shown to track into adulthood [38, 2] and are linked to future cardiovascular disease (CVD) risk [39, 30].

While there have been reviews of the benefits of health-related fitness in youth and the importance of MF for CVD risk reduction [2, 31], it appears no previous systematic review has examined the association between MF in youth and the range of physiological and psychological benefits. Therefore, the purpose of this review is to systematically examine the association between MF in children and adolescents and the potential health benefits in each of these domains.

2. Methods

2.1 Identification of studies

A systematic search of six electronic databases (PubMed, SPORTDiscus, Scopus, Embase, PsycINFO and OVID MEDLINE) was performed on 20th May, 2013 following consultation with an academic librarian. The following search strings were used: Musc* AND (strength OR endurance OR power) OR ("resistance training" OR "weight training") AND (adolescen* OR teen* OR child* OR student* OR youth* OR school* OR young*) AND (health OR risk OR consequence* OR benefit* OR psych* OR behavio* OR effect*). No limits on date of publication were imposed however only articles published in refereed journals and in English language were considered for review. Conference proceedings, abstracts and theses were not included. Relevant articles were identified through two stages of screening performed independently and compared by two researchers. In the first stage, titles and abstracts of the search results were checked for relevance. In the second stage, full texts were located and assessed for eligibility. The reference lists of all included articles and previous reviews on the topic were also checked to identify any articles that were not located through the database search.

2.2 Criteria for inclusion/exclusion

Two authors independently assessed the eligibility of studies based on the following criteria: (i) Study participants were school-aged youth (i.e., 4-19 years) in the general population. Studies with targeted groups from special populations were excluded (e.g., athletes, clinically obese, subjects with mental illness etc). Although studies have found that resistance training may be protective against sports-related injuries [11], the benefits of MF for young athletes was beyond the scope of this review; (ii) Study provided a quantitative assessment of MF (e.g., strength, power or local muscular endurance); (iii) Study provided a quantitative assessment of at least one potential benefit (e.g., insulin resistance, adiposity, self-esteem etc); (iv) Study provided a quantitative analysis of the association between MF and the potential benefit(s); and, (v) Published in English in a peer reviewed journal. Following independent assessment of eligibility, the two lists of included articles were compared. Any discrepancies were discussed and agreed upon prior to inclusion or exclusion. Consensus was reached on all articles included in the review.

2.3 Criteria for risk of bias assessment

Two authors independently assessed the risk of bias of included studies, which occurred at the study level. The criteria for assessing risk of bias was based on the Consolidated Standards of Reporting Trials (CONSORT) statement [40] and the Studies in Epidemiology (STROBE) statement [41]. A risk of bias score was allocated to each study by assigning a value of 0 (criteria not met) or 1 (criteria met) based on the following: (i) Study sites or participants were randomly selected and the randomization procedure was adequately described; (ii) Adequate description of the study sample (i.e., number of participants, mean age and sex); (iii) Adequate assessment/reporting of MF (i.e., validity/reliability of fitness test reported and/or detailed description of testing protocols); (iv) Adequate assessment of the potential benefit (i.e., validity/reliability of outcome measure reported and/or measurement procedure adequately described) and (v) Adjustment for confounders (i.e., age and sex) in the statistical analyses where necessary. The scores for each criterion were summed to provide a total score out of 5. Studies that scored 0-2 were considered to have a 'high risk' of bias, those that scored 3 were considered to have a 'moderate risk' of bias, and those scoring 4-5 were considered to have a 'low risk' of bias. Inter-rater agreement for the risk of bias assessment was determined by the percentage agreement between raters. Furthermore, *Kappa* analysis was conducted using SPSS software, version 21.0 (SPSS Inc, Chicago, Illinois).

2.4 Categorization of variables and level of evidence

Data were extracted into an Excel spreadsheet using a template designed specifically for the review. A separate author checked all of the extracted data for accuracy. If any additional data (e.g., coefficients for the associations) were required, the corresponding author of the included study was contacted by email. The outcome variable(s) of each study were grouped into two broad categories: 'physiological' (e.g., adiposity) and 'psychological and cognitive' (e.g., self-esteem). Results were coded using the method first employed by Sallis et al. [42], and more recently used by Lubans et al. [43]. If 0-33% of studies reported a significant association, the result was classified as no association (0). If 34-59% of studies reported a significant association or if fewer than four studies reported on the outcome, the result was classified as being inconsistent/uncertain (?). If ≥60% of studies found a significant association, the result was classified as positive (+) or negative (-) depending on the direction of the association. Additional coding was performed to account for risk of bias using the method proposed by Lubans et al. [43]. If ≥60% of studies with low risk of bias found a significant association then the result was classified as strong positive (++) or strong negative (- -) depending on the direction of the association. If studies employed multiple analyses, only findings from the highest level of analysis (i.e., multivariate) were considered.

2.5 Meta-analyses

Meta-analyses were conducted to determine the pooled effect size between MF and the outcome of interest. Meta-analyses were conducted if at least three studies provided standardized coefficients between MF and potential benefits. Analyses were conducted using comprehensive meta-analysis software, version 2 for Windows (Biostat company, Englewood NJ, USA) [44] with random effects models. Heterogeneity was determined by Cochrane's Q statistic and I^2 values. For interpretation, I^2 values of 25, 50, and 75 were considered to indicate low, moderate and high heterogeneity, respectively [45]. Publication bias was analysed using Rosenthal's *classic fail-safe N* [46] and Duval and Tweedie's *trim and fill* procedure [47]. Correlations between variables were interpreted as follows: 0-0.19 (no correlation), 0.2-0.39 (low correlation), 0.4-0.59 (moderate correlation), 0.6-0.79 (moderately high correlation), and ≥0.8 (high correlation) [48].

3. Results

3.1 Overview of studies

The systematic search yielded 2666 potentially relevant articles following the removal of duplicates (Figure 1). After full text screening and checking the reference lists of included studies and previous reviews for additional relevant articles, a total of 110 studies were included. Of the included studies, 86 were cross-sectional, 20 were longitudinal and four were experimental. The number of study participants ranged from 20 [49] to 1,142,599 [30]. Further details on study characteristics are presented in Electronic Supplementary Material Table S1.

3.2 Overview of study quality

There was 95% agreement between raters for risk of bias and consensus was achieved on all included studies following discussion. Inter-rater agreement was found to be high (*Kappa* = 0.86, $p < 0.001$). The results of the risk of bias assessment can be found in Electronic Supplementary Material Table S2. Overall, one study (1%) was considered to have a high risk of bias, 34 studies (31%) were considered to have a moderate risk of bias, and 75 studies (68%) were considered to have a low risk of bias. 'Random selection of study sites or participants' was the most poorly satisfied criterion with 54 studies

(49%) scoring zero. The most consistently satisfied criterion was ‘adequate description of the study sample’ with only four studies (4%) scoring zero.

3.3 Physiological benefits

A summary of the associations between MF and each of the potential benefits can be found in Table 1.

3.3.1 Adiposity

Fifty-one studies reported on the association between MF and measures of adiposity (e.g., body mass index [BMI], sum of skinfolds, waist circumference [WC] etc). Forty-two studies were cross-sectional, seven were longitudinal, and two were experimental. A number of measures were used, both between and within studies, to measure adiposity. These measures can be broadly classified as measuring either total body fatness (e.g., BMI) or central body fatness (e.g., WC). Of the 48 studies reporting on the association between MF and measures of total body fatness, 43 (90%) reported significant inverse associations. These associations were generally low-to-moderate. Nine of these studies however, also reported a significant positive association between one measure of MF and adiposity. Positive associations were only found for tests of MF in which the subject was not required to support their body weight during movement (e.g., handgrip strength). Performance in MF tests in which the subject was required to either lift their body weight (e.g., curl ups, push ups) or propel their body through space (e.g., vertical jump, standing long jump) was consistently found to be inversely associated with adiposity. Of the 37 studies with a low risk of bias, 33 (89%) found a significant association providing strong evidence of an inverse association with MF.

Fourteen studies examined the association between MF and central adiposity, which was most commonly measured by WC. Thirteen studies were classified as having low risk of bias. Overall, ten studies (71%) found a significant association as did nine (69%) studies with a low risk of bias suggesting strong evidence of an inverse association between MF and central adiposity. There was one instance of a positive association being reported between handgrip strength and WC [50]. The associations for central adiposity were also generally low-to-moderate in magnitude.

A meta-analysis was conducted to determine the pooled effect size between MF and adiposity. All studies reporting partial correlation coefficients between MF and any adiposity variable were included. Using a random effects model, the pooled effect size was *r* = -0.29 (95% CI = -0.44 to -0.12), *Z* = -3.33, *p* = 0.001. Significant between-study heterogeneity was observed, *Q*(7) = 174.89, *p* = <0.001 and I^2 (96.00) indicated that 96% of the observed variance was explained by true systematic effect size differences. Publication bias was considered unlikely with Rosenthal's *fail-safe N* [46] indicating that 686 unpublished studies with an effect size of zero would be required to alter the point estimate to not being statistically significant. However, Duval and Tweedie's *trim and fill* procedure, which attempts to improve the symmetry of smaller studies around the point estimate within the funnel plot, detected an asymmetrical distribution. Consequently, one study was trimmed and the adjusted effect size was slightly weaker (*r* = -0.25, 95% CI = -0.41 to -0.08).

3.3.2 Bone health

Seventeen studies examined the association between MF and measures of bone health. Thirteen studies were cross-sectional, three were longitudinal, and one was experimental. Bone mineral density, bone mineral content, and bone area were the most commonly examined indices of bone health in included studies and one study [51] investigated the effect of muscular strength on fracture risk. Overall, 12 studies (71%) reported a significant association. Of the nine low risk of bias studies, eight (89%) reported a statistically significant finding suggesting strong evidence of positive association. The evidence from prospective studies was less conclusive. Of the three longitudinal studies [52-54], two [53, 54] found that MF and bone mass were significantly related. However, in the only randomized controlled trial (RCT) [55], changes in MF were not significantly related to changes in bone mass.

3.3.3 CVD and metabolic risk factors

Twenty studies examined the association between MF and CVD and metabolic risk factors. Fifteen studies were cross-sectional and five were longitudinal. Overall, 15 studies (75%) found a significant association. Of the 17 low risk of bias studies, 13 (76%) reported that CVD and metabolic risk factors were significantly associated with MF, suggesting strong evidence of an inverse association. Strong evidence was found for an association between MF and clustered CVD risk with six (86%) of the seven studies examining this outcome reporting statistically significant findings. MF was also found to be significantly related to insulin resistance [32, 56, 57], inflammatory biomarkers [58-62], and both all-cause mortality and mortality due to CVD [63].

3.3.4 Musculoskeletal pain

Fifteen studies examined the association between MF and musculoskeletal pain. Nine were cross-sectional and six were longitudinal. These studies generally investigated the role of local muscular endurance of the trunk flexors and extensors in relation to lower back or neck pain. Overall, nine studies (60%) reported finding a significant inverse association between MF and musculoskeletal pain. Of the eight low risk of bias studies, four (50%) found that MF and pain symptoms were significantly associated suggesting inconsistent/uncertain evidence of an inverse association. The results of longitudinal studies were equivocal with three [64-66] of the six studies reporting that MF and musculoskeletal pain were related.

3.4 Psychological and cognitive benefits

3.4.1 Psychological benefits

Eight studies, seven cross-sectional and one experimental, investigated the association between MF and psychological benefits. Six were classified as having a low risk of bias. Six studies investigated the association between MF and self-esteem/physical self-perceptions, while the remaining studies investigated other psychological indices including life satisfaction, depressed mood, and risk of mental illness and suicide. Of the studies investigating the link between MF and self-esteem/physical self-perceptions, five (83%) found a significant association for one or a number of constructs. Self-perceptions were examined using instruments developed for the general population. However, the names of certain subscales can vary between instruments. For example, Harter’s self-perception profile for adolescents [67] measures perceived *athletic* competence whereas Whitehead’s children’s self-perception profile [68] measures perceived *sports* competence. Similar subscales were grouped together for this summary. The constructs shown to be consistently related with MF were perceived physical appearance (including perceived body fatness) [69-71], perceived sports competence (including perceived athletic competence and physical ability) [69-71], overall physical self-worth [72, 71] and global self-esteem [73, 71]. Conversely, the single experimental study [49] showed that changes in MF were not related to changes in any physical self-perceptions. The studies investigating other psychological outcomes also generally reported significant findings.

A meta-analysis was conducted to determine the pooled effect size between perceived sports competence and MF, as this was the only construct for which data were available from at least three studies. The random effects model yielded an overall effect size of $r = 0.42$ (95% CI = 0.36 to 0.47), $Z = 12.55$, $p < 0.001$, indicating a moderate positive association. Between-study heterogeneity was not significant $Q(4)= 8.35$, $p = 0.08$. However, I^2 (52.09) indicated that 52% of the observed variance could be explained by systematic differences in effect sizes, suggesting moderate heterogeneity. Publication bias was considered unlikely as demonstrated by Rosenthal's *classic fail-safe N* [46], which indicated that 471 unpublished studies with an effect size of zero would be required to cause the pooled point estimate to become statistically insignificant. Duval and Tweedie's *trim and fill* procedure [47] detected asymmetry in the distribution of observed effect sizes. Consequently, the adjusted value became slightly weaker ($r = 0.39$, 95% CI = 0.34 to 0.45).

3.4.2 Cognitive benefits

Six studies investigated the association between MF and cognitive benefits (e.g., academic performance), all of which were cross-sectional. Four studies were considered to have a low risk of bias. Of the six included studies, three (50%) reported a significant association between MF and cognitive ability. Only one of the low risk of bias studies reported a significant association, suggesting inconsistent/uncertain evidence of an association between MF and cognitive benefits.

4. Discussion

4.1 Overview of findings

The aim of this systematic review and meta-analyses was to comprehensively evaluate the range of physiological and psychological health benefits associated with MF among children and adolescents. Overall, 110 studies encompassing six health outcomes (i.e., adiposity, bone health, CVD and metabolic risk factors, musculoskeletal pain, psychological health and cognitive ability) were reviewed.

Strong evidence for an inverse association with MF was found for adiposity, and CVD and metabolic risk factors. We also found strong evidence for a positive association between MF and bone health and self-esteem (including physical self-concept, perceived physical appearance, and perceived sports competence). The evidence of an association between MF and musculoskeletal pain and cognitive ability was considered to be inconsistent/uncertain.

4.2 Physiological benefits

4.2.1 Adiposity

The findings of this review provide strong evidence of an inverse association between MF and both total and central adiposity. The associations were generally low-to-moderate as demonstrated by the pooled effect size of $r = -0.25$. Excess body fat was consistently associated with poor performance in MF tests that require lifting or propulsion of the body mass. Notably, data from the healthy lifestyle in Europe by nutrition in adolescence (HELENA) study [50], adjusted for multiple confounders, showed consistent moderate inverse associations between jumping-based MF tests and adiposity measured using multiple methods including dual-energy X-ray absorptiometry. Cross-sectional evidence was supported by longitudinal studies which showed reductions in adiposity over time with increases in muscle strength[74-76]. Furthermore, in a large sample of nearly 2800 US children [77] it was found that both achieving and maintaining ‘adequate’ MF over a four-year period resulted in significantly greater odds of being a healthy weight at follow-up.

These data are suggestive of a cause and effect association by which improvements in MF lead to reductions in body fatness. The specific mechanisms through which this may occur are likely to be complex, numerous and interacting. However, as obesity is driven by an energy imbalance [78], with energy surplus being stored as fat tissue, it can reasonably be hypothesized that the protective effects of MF are related to its role in energy expenditure. Skeletal muscle is known to be a highly energetic tissue, contributing substantially to basal metabolic rate [79]. Therefore, improvements in MF may reflect increases in skeletal muscle mass, the metabolic efficiency of muscle (i.e., lipid oxidation and glucose transport capacity) or both, resulting in greater overall daily energy expenditure [79, 50]. Improvements in MF may also make physical activity easier to perform and hence more enjoyable [80], resulting in greater activity energy expenditure over time. However, this association is probably bidirectional with increases in both fitness and fatness likely to impact on physical activity participation [50, 81].

Contrary to the findings of weight-bearing MF tests, the literature consistently showed a positive association between handgrip strength and adiposity. A number of investigators have attributed this to higher levels of lean mass among the overweight youth [50, 82]. However, Artero et al. [83] found that, at least for boys, the higher handgrip strength observed among overweight adolescents could not be explained by differences in fat-free mass, concluding that unmeasured morphological and/or neurological factors might be influencing the association. While it is possible that weight-bearing tests of MF (i.e., standing long jump, vertical jump etc) are simply capturing variation in body mass and not necessarily variation in MF, we do not believe this to be the case. Milliken et al., [84], found that vertical jump and standing long jump performance were significant predictors of 1RM leg press, the criterion measure of lower body strength. Therefore, these tests can be considered appropriate for assessing the relationship between MF and health outcomes. Further, longitudinal studies have shown that changes in MF measured both in absolute terms [76] and relative to body weight [75, 74] are inversely associated with adiposity. Despite the apparent contradiction there appears to be clear evidence of the importance of MF for adiposity among youth, which may occur through both physiological and psycho-behavioural mechanisms.

4.2.2 Bone health

Youth has been identified as a critical stage for determining lifelong skeletal health [79]. During puberty in particular bone tissue is highly responsive to osteogenic stimuli [55]. This has led researchers to investigate the potential of optimising peak bone mass during youth for the primary prevention of osteoporosis in adulthood [85, 86]. A high bone mass during youth is also protective against the risk of immediate fracture [87], especially as participation in 'risky' physical activities is highest during this time [79]. While peak bone mass is predominantly determined by genes [88], a number of modifiable determinants including physical activity, calcium intake and MF have been identified [89-91]. The findings of our review support the latter with the majority of low risk of bias studies demonstrating a significant association between MF and bone health. However, as the majority of studies were cross-sectional, we are unable to form strong conclusions regarding the prospective association between MF and bone health. In one of the few longitudinal studies, Cheng et al. [52]

found that MF was not a predictor of bone mass among a sample of Asian adolescents. However, bone mass is in part racially determined [92, 93] and consequently these findings may not be generalizable to different ethnic groups. In a school-based RCT, Weeks et al. [55] found that changes in bone mass measured at multiple sites could be explained by changes in lean mass but not by changes in MF. Alternatively, a 20-year follow-up study found site specific associations between curl ups performance during adolescence and bone mineral density in adulthood [54].

One consistent finding between studies was of the importance of lean mass in explaining bone mass variation. Lean mass was found to be a strong predictor of bone mass, in some cases independently explaining more than 60% of the observed variance [33, 94]. Associations between MF and bone mass on the other hand were considerably weaker. As improvements in muscular performance would be expected to accompany increases in lean mass, MF may be most useful as an inexpensive and reproducible surrogate for lean mass; enabling the identification of youth with a heightened risk of poor skeletal health [33]. Alternatively, MF may be a proxy for past physical activity, indirectly influencing bone mineralization through increasing lean mass during pubertal growth [95]. More longitudinal and experimental studies are required to ascertain the relative contribution of physical activity and MF - and their interaction with lean mass - to improvements in bone health. Regardless, the rationale for increasing peak bone mass during youth through activities that both require and develop MF appears sound.

4.2.3 CVD and metabolic risk factors

While the clinical symptoms of CVD typically manifest in adulthood, evidence suggests that the genesis of CVD occurs in youth; with elevated levels and clustering of known risk factors evident in childhood [96, 97]. As CVD risk factors track from youth to adulthood [98], adolescence represents an opportunity to mitigate population-level health burden through preventive strategies. The studies included in this review provide strong evidence for the importance of MF during youth for CVD risk and extend on the inconclusive findings from an earlier systematic review [31]. In addition to clustered CVD risk, studies also demonstrated that MF was associated with insulin resistance [32, 56, 57], inflammatory biomarkers [58-62] and both all-cause and CVD-related mortality [30]. .

CRF is known to be a strong predictor of CVD risk [2] but importantly, MF was found to be associated with CVD risk independent of CRF and other confounders [56, 57]. This was confirmed longitudinally among Danish adolescents taking part in the European Youth Heart Study [39], suggesting that there is both a combined and additive effect of MF on CVD outcomes. The association was found to be non-linear with the greatest benefits achieved by increasing MF levels from low to moderate and little additional benefit received thereafter [56, 99, 57]. Interestingly, the protective effect of MF was found to be most distinct amongst overweight youth [56, 57]. This finding is encouraging as overweight youth are a group already at increased risk of CVD and metabolic disorders in later life [100, 101]. Increasing MF in overweight youth, particularly from low to moderate, may be an effective strategy for improving the health trajectory of this 'at risk' group. Additionally, overweight youngsters tend to experience greater self-efficacy and enjoyment in MF-based activities compared to those that demand a greater cardio-respiratory capacity [102]. Intervention programs involving a 'muscular' focus (e.g., resistance training) may therefore result in greater adherence and satisfaction among overweight youth, as demonstrated in previous studies [103, 104]. Future research should determine the clinical significance of changes in MF during youth for CVD and metabolic outcomes in later life [39].

4.2.4 Musculoskeletal pain

A sharp increase in musculoskeletal pain symptoms has been observed during the time around puberty [105] and pain symptoms during youth have been shown to predict pain in adulthood [106]. Furthermore, the prevalence of back pain among children and adolescents may be as high as 25% [107]. The findings of studies included in this review were equivocal indicating that the association between MF and musculoskeletal pain remains unclear, which is consistent with the findings of an earlier review [31]. While some studies found that increased trunk muscle strength and local muscular endurance were protective against back and neck pain, others found no association. One study reported that greater back strength increased the risk of low back pain [108] while another reported that both reduced and greater back muscular endurance were associated with back pain [109]. It is important to note that cross-sectional studies cannot determine causality and reverse causation is equally plausible – low activity levels and poor MF may cause back pain or vice versa [110]. Evidence from longitudinal studies should confirm or refute causality but at present they too appear somewhat equivocal. The available evidence currently supports the potential for an inverse association between MF and musculoskeletal pain. However, more high quality longitudinal investigations are required to confirm previous findings and explain the contradictory reports identified within other studies.

4.3 Psychological and cognitive benefits

4.3.1 Psychological benefits

Poor mental health is a significant public health issue for youth [111] and mental illness is expected to be the leading disease burden globally by 2020 [112]. Identifying the determinants of mental health problems is important for informing public health strategies, particularly those with a preventive focus. Global self-esteem, an important element of well-being [113], is typically considered to be at the apex of a hierarchical framework made up of domain specific constructs (i.e., physical self-worth), which are further subdivided into specific self-perceptions [71]. The findings of this review suggest evidence of an association between MF and physical self-perceptions namely, perceived physical appearance (including perceived body fatness) and perceived sports competence (including perceived physical ability and athletic competence). Furthermore, there is evidence for an association between MF and overall physical self-worth and global self-esteem. According to Harter's competence motivation theory, actual competence precedes perceived competence in the causal pathway [114]. Perceptions of competence are hypothesised to subsequently influence physical activity participation through decreased motivation to be active. As suggested by Stodden et al. [115] this can result in a self-perpetuating cycle of disengagement among less capable youth. Successful sports performance is largely dependent on fitness-related attributes, therefore the moderate association found between MF and perceived sports competence is not overly surprising. However, this association reinforces the argument for developing adequate fitness, particularly during childhood, in order to improve opportunities for success and increase the likelihood of lifelong physical activity. Increasing physical activity can be considered an important public health objective not only for the known physical health benefits but also for its role in the prevention and treatment of psychological ill health [116]. The finding that a low level of muscular strength during adolescence was associated with a greater risk of psychiatric diagnosis and suicide in later life [30] highlights the relevance of MF for positive psychological health.

4.3.2 Cognitive benefits

There was considerable heterogeneity between measures used to assess cognitive ability making comparisons between these particular studies problematic. As such, these findings must be interpreted with caution. In addition, as all of the studies reviewed herein were cross-sectional, no evidence on causality can be provided. The evidence for an association between MF and cognitive ability was considered inconsistent/uncertain. While Dwyer et al. [117] found significant associations between MF and 'scholastic ability' among 7-15 year old youth, this was a subjective rating made on a simple 5-point scale and therefore may not represent true academic ability. Coe et al. [35] and Du Toit et al. [118] also reported significant associations between MF and academic performance, but analyses were not adjusted for important covariates. Alternatively, the studies that controlled for potential confounders such as age and sex [119-121], found no association between MF and academic ability. Previous research has linked CRF and physical activity to cognitive ability [122, 123] however, it is unknown whether physical activity and CRF improve cognitive functioning or whether they are simply markers of motivated and high achieving youth [121]. Potential mechanisms for this association have been hypothesized and include neuroplastic responses from increased blood flow and the release of brain derived neurotrophic factor [124]. Alternatively, CRF may influence executive control enabling better performances in complex cognitive tasks [125]. While there appears to be support for the importance of CRF, the available evidence is unclear on the link between MF and cognitive ability.

4.4 Strengths and limitations

Although other reviews on this topic are available [2, 31], they have focused on the benefits and 'predictive validity' of health-related fitness in general. While longitudinal data can provide stronger evidence for the link between MF and health, it is important to acknowledge and review evidence from cross-sectional studies. To the authors' knowledge this is the first review to provide a systematic and comprehensive evaluation of the range of physiological and psychological benefits associated with MF among children and adolescents. Furthermore, our review provides an update of the evidence reported within earlier reviews. Strengths of our review include the large number of included studies covering a variety of relevant domains and additional coding for risk of bias in the quantitative synthesis. However, the former also introduced some limitations. Discussion of the broad range of potential benefits of MF precluded a more detailed examination of potential moderators of the observed associations. Whether or not the associations were moderated by age, sex or ethnicity is likely to be of importance to researchers, physical educators and health professionals. However, this was beyond the scope of our review. Further, it must be noted that we did not review the benefits of MF for the prevention of sports-related injuries. Previous research has indicated that resistance training as part of a preparatory conditioning program is effective for reducing the risk of injury during sports participation [11]. However, in order for our review to be generalizable to the wider youth population we excluded studies specifically targeting young athletes during the screening process. Additionally, as inactive children are at greater risk of injury in both physical education and leisure-time physical activity contexts [126], resistance training may also assist those not participating in organized sport to safely engage in physical activity.

4.5 Future research

The paucity of longitudinal and experimental studies prevented us from drawing stronger conclusions on causal relationships for a number of outcomes. Experimental studies have measured changes in MF and the outcomes included in this review [127, 128, 103, 129]. However, these studies often focus on examining time and group effects, and usually fail to investigate the *association* between changes in MF and changes in the outcome. In this respect, the importance of MF specifically for these outcomes can be deduced but not confirmed. More high quality longitudinal and experimental studies are required to investigate causality and to determine the clinical significance of changes in MF for health-related outcomes. In particular, further study of the effects of MF on psychological well-being is needed. Large scale longitudinal studies examining the effect of resistance training or changes in MF on aspects of cognitive ability (i.e., executive function) are also warranted. Few studies included in our review reported standardised coefficients, preventing more comprehensive meta-analyses of the associations between MF and potential benefits. Future studies should report standardised coefficients to allow for simpler comparisons of study findings and to enable more thorough meta-analyses of the associations between MF and health outcomes. Finally, as was evident in studies examining the relationship between MF and adiposity, the association can change - and even reverse - depending on whether an ‘absolute’ or ‘relative’ (i.e., divided by body mass) measure of MF is used. In future studies, investigators should consider the type of MF test used and decide on the most appropriate method for expressing MF in their analyses. As many weight-bearing MF tests are highly correlated with body mass/adiposity [130], analyses of the relationship between MF and the health outcome of interest should adjust for these variables in order to ascertain the independent contribution of MF.

5. Conclusions

This systematic review comprehensively evaluated the range of potential benefits of MF among children and adolescents. We conclude that:

i) There is strong evidence for a positive association between MF and bone health and self-esteem, although the associations are low-to-moderate;

ii) There is strong evidence of an inverse association between MF and total and central adiposity, and CVD and metabolic risk factors, although the associations are also low-to-moderate; and

iii) The associations between MF and musculoskeletal pain and cognitive ability are inconsistent/uncertain.

The findings of this review lend support to current physical activity guidelines that recommend youth regularly engage in muscle-strengthening physical activities [12]. School- and community-based youth programs should include activities that develop muscular strength, local muscular endurance and muscular power in addition to other health- and skill-related components of physical fitness. These findings are of relevance to physical educators, health care professionals, policy makers, and researchers interested in paediatric health.

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References

1. Casazza K, Gower BA, Willig AL et al. Physical fitness, activity, and insulin dynamics in early pubertal children. Pediatr Exerc Sci. 2009;21(1):63.

2. Ortega F, Ruiz J, Castillo M et al. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes. 2008;32(1):1-11.

3. Blair SN, Cheng Y, Holder JS. Is physical activity or physical fitness more important in defining health benefits? Med Sci Sports Exerc. 2001;33(6; SUPP):S379-S99.

4. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126.

5. Freedson PS, Cureton KJ, Heath GW. Status of field-based fitness testing in children and youth. Prev Med. 2000;31(2):S77-S85.

6. Trost S. Discussion paper for the development of recommendations for children's and youth's participation in health promoting physical activity. Queensland: School of Human Movement Studies. 2005.

7. Gallahue DL, Ozman JC. Understanding motor development: Infants, children, adolescents, adults. 6th ed. Boston: McGraw-Hill; 2006.

8. Jinguji T. Muscular strength and muscular endurance: What is the “true” definition for physical educators? In: Innovations 4 PE. Jinguji Consulting, LLC, Roseville, CA 2008. www.innovations4pe.com. Accessed 14/01/2013 2013.

9. Beunen G, Thomis M. Muscular strength development in children and adolescents. Pediatr Exerc Sci. 2000;12:174-97.

10. Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. 2nd ed. Champaign, IL: Human Kinetics; 2004.

11. Faigenbaum AD, Myer GD. Resistance training among young athletes: safety, efficacy and injury prevention effects. Br J Sports Med. 2010;44(1):56-63.

12. Organization WH. Global recommendations on physical activity for health. Geneva: World Health Organization. Geneva: World Health Organization.; 2010. p. 8-10.

13. Lloyd RS, Faigenbaum AD, Stone MH et al. Position statement on youth resistance training: the 2014 International Consensus. Br J Sports Med. 2013.

14. Tomkinson GR, Olds TS. Secular changes in pediatric aerobic fitness test performance: the global picture. Karger Publishers; 2007.

15. Tomkinson GR, Olds TS. Secular changes in aerobic fitness test performance of Australasian children and adolescents in: Pediatric Fitness. Secular trends and Geographic Variability. Medicine & Sports Science. 2007;50:168-82.

16. Tomkinson GR, Léger LA, Olds TS et al. Secular trends in the performance of children and adolescents (1980–2000). Sports Med. 2003;33(4):285-300.

17. Pitetti KH, Beets MW. A comparison of shuttle-run performance between Midwestern youth and their national and international counterparts. Pediatr Exerc Sci. 2004;16(2):94-112.

18. Sandercock G, Voss C, McConnell D et al. Ten year secular declines in the cardiorespiratory fitness of affluent English children are largely independent of changes in body mass index. Arch Dis Child. 2010;95(1):46-7.

19. Adams J. Trends in physical activity and inactivity amongst US 14–18 year olds by gender, school grade and race, 1993–2003: evidence from the youth risk behavior survey. BMC Public Health. 2006;6(1):57.

20. Cohen DD, Voss C, Taylor MJD et al. Ten-year secular changes in muscular fitness in English children. Acta Paediatr. 2011;100(10):e175-e7. doi:http://dx.doi.org/10.1111/j.1651-2227.2011.02318.x.

21. Moliner-Urdiales D, Ruiz J, Ortega F et al. Secular trends in health-related physical fitness in Spanish adolescents: The AVENA and HELENA Studies. J Sci Med Sport. 2010;13(6):584-8.

22. Runhaar J, Collard D, Singh A et al. Motor fitness in Dutch youth: differences over a 26-year period (1980–2006). J Sci Med Sport. 2010;13(3):323-8.

23. Matton L, Duvigneaud N, Wijndaele K et al. Secular trends in anthropometric characteristics, physical fitness, physical activity, and biological maturation in Flemish adolescents between 1969 and 2005. Am J Hum Biol. 2007;19(3):345-57.

24. Aires L, Andersen LB, Mendonça D et al. A 3 ‐ year longitudinal analysis of changes in fitness, physical activity, fatness and screen time. Acta Paediatr. 2010;99(1):140-4.

25. Westerstahl M, Barnekow-Bergkvist M, Hedberg G et al. Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. Scand J Med Sci Sports. 2003;13(2):128-37.

26. Ruiz JR, Castro-Piñero J, España-Romero V et al. Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. Br J Sports Med. 2011;45(6):518-24.

27. Ortega FB, Artero EG, Ruiz JR et al. Physical fitness levels among European adolescents: the HELENA study. Br J Sports Med. 2011;45(1):20-9.

28. Ruiz JR, Sui X, Lobelo F et al. Association between muscular strength and mortality in men: prospective cohort study. Br Med J. 2008;337(7661):92.

29. FitzGerald SJ, Barlow CE, Kampert JB et al. Muscular fitness and all-cause mortality: prospective observations. J Phys Act Health. 2004;1:7-18.

30. Ortega FB, Silventoinen K, Tynelius P et al. Muscular strength in male adolescents and premature death: Cohort study of one million participants. BMJ (Online). 2012;345(7884):1-12.

31. Ruiz JR, Castro-Piñero J, Artero EG et al. Predictive validity of health-related fitness in youth: a systematic review. Br J Sports Med. 2009;43(12):909-23.

32. Benson AC, Torode ME, Fiatarone Singh MA. Muscular strength and cardiorespiratory fitness is associated with higher insulin sensitivity in children and adolescents. Int J Pediatr Obes. 2006;1(4):222-31. doi:10.1080/17477160600962864.

33. Vicente-Rodríguez G, Urzanqui A, Mesana MI et al. Physical fitness effect on bone mass is mediated by the independent association between lean mass and bone mass through adolescence: a cross-sectional study. J Bone Miner Metab. 2008;26(3):288-94.

34. Padilla-Moledo C, Ruiz JR, Ortega FB et al. Associations of muscular fitness with psychological positive health, health complaints, and health risk behaviors in Spanish children and adolescents. J Strength Cond Res. 2012;26(1):167-73. doi:10.1519/JSC.0b013e31821c2433.

35. Coe DP, Pivarnik JM, Womack CJ et al. Health-related fitness and academic achievement in middle school students. J Sports Med Phys Fitness. 2012;52(6):654-60.

36. Myer GD, Faigenbaum AD, Chu DA et al. Integrative training for children and adolescents: techniques and practices for reducing sports-related injuries and enhancing athletic performance. Phys Sportsmed. 2011;39(1):74.

37. Vaughn JM, Micheli L. Strength training recommendations for the young athlete. Phys Med Rehabil Clin N Am. 2008;19(2):235-45.

38. Castillo-Garzon M, Ruiz J, Ortega F et al. A mediterranean diet is not enough for health: physical fitness is an important additional contributor to health for the adults of tomorrow. World Rev Nutr Diet. 2006;97:114-38.

39. Grøntved A, Ried-Larsen M, Møller NC et al. Muscle strength in youth and cardiovascular risk in young adulthood (the European Youth Heart Study). Br J Sports Med. 2013. doi:10.1136/bjsports-2012-091907.

40. Moher D, Schulz KF, Altman DG. The CONSORT statement: revised recommendations for improving the quality of reports of parallel group randomized trials. BMC Med Res Methodol. 2001;1(1):2.

41. von Elm E, Altman DG, Egger M et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Prev Med. 2007;45(4):247-51.

42. Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. Med Sci Sports Exerc. 2000;32(5):963-75.

43. Lubans DR, Morgan PJ, Cliff DP et al. Fundamental movement skills in children and adolescents. Sports Med. 2010;40(12):1019-35.

44. Borenstein M, Hedges L, Higgins J et al. Comprehensive meta-analysis version 2. Englewood, NJ: Biostat. 2005.

45. Higgins JP, Thompson SG, Deeks JJ et al. Measuring inconsistency in meta-analyses. Br Med J. 2003;327(7414):557.

46. Rosenthal R. The file drawer problem and tolerance for null results. Psychol Bull. 1979;86(3):638.

47. Duval S, Tweedie R. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta‐analysis. Biometrics. 2000;56(2):455-63.

48. Safrit MJ, Wood TM. Introduction to measurement in physical education and exercise science. Times Mirror/Mosby St-Louis, MO; 1986.

49. Ransdell LB, Detling NJ, Taylor A et al. Effects of Home- and University-based programs on physical self-perception in mothers and daughters. Women Health. 2004;39(2):63-81. doi:10.1300/J013v39n02_05.

50. Moliner-Urdiales D. Associations of muscular and cardiorespiratory fitness with total and central body fat in adolescents: The HELENA Study. Br J Sports Med. 2011;45(2):101-8.

51. Clark EM, Tobias JH, Murray L et al. Children with low muscle strength are at an increased risk of fracture with exposure to exercise. J Musculoskelet Neur Interac. 2011;11(2):196-202.

52. Cheng JCY, Maffulli N, Leung SSSF et al. Axial and peripheral bone mineral acquisition: A 3-year longitudinal study in Chinese adolescents. Eur J Pediatr. 1999;158(6):506-12. doi:10.1007/s004310051131.

53. Wang Q, Alen M, Nicholson P et al. Weight-bearing, muscle loading and bone mineral accrual in pubertal girls-A 2-year longitudinal study. Bone. 2007;40(5):1196-202. doi:10.1016/j.bone.2006.12.054.

54. Barnekow‐Bergkvist M, Hedberg G, Pettersson U et al. Relationships between physical activity and physical capacity in adolescent females and bone mass in adulthood. Scand J Med Sci Sports. 2006;16(6):447-55.

55. Weeks BK, Young CM, Beck BR. Eight months of regular in-school jumping improves indices of bone strength in adolescent boys and girls: The POWER PE study. J Bone Miner Res. 2008;23(7):1002-11. doi:10.1359/jbmr.080226.

56. Artero EG, Ruiz JR, Ortega FB et al. Muscular and cardiorespiratory fitness are independently associated with metabolic risk in adolescents: The HELENA study. Pediatr Diabetes. 2011;12(8):704-12. doi:10.1111/j.1399-5448.2011.00769.x.

57. Steene-Johannessen J, Anderssen SA, Kolle E et al. Low muscle fitness is associated with metabolic risk in youth. Med Sci Sports Exerc. 2009;41(7):1361-7. doi:10.1249/MSS.0b013e31819aaae5.

58. Artero E, España-Romero V, Jiménez-Pavón D et al. Muscular fitness, fatness and inflammatory biomarkers in adolescents. Pediatr Obes. 2013.

59. Martinez-Gomez D, Eisenmann JC, Gomez-Martinez S et al. Associations of physical activity and fitness with adipocytokines in adolescents: The AFINOS study. Nutr Metab Cardiovasc Dis. 2012;22(3):252-9. doi:10.1016/j.numecd.2010.07.010.

60. Martinez-Gomez D, Gomez-Martinez S, Ruiz JR et al. Objectively-measured and self-reported physical activity and fitness in relation to inflammatory markers in European adolescents: The HELENA Study. Atherosclerosis. 2012;221(1):260-7. doi:10.1016/j.atherosclerosis.2011.12.032.

61. Ruiz JR, Ortega FB, Wärnberg J et al. Inflammatory proteins and muscle strength in adolescents: the AVENA study. Arch Pediatr Adolesc Med. 2008;162(5):462-8.

62. Steene-Johannessen J, Kolle E, Bo Andersen L et al. Adiposity, aerobic fitness, muscle fitness, and markers of inflammation in children. Med Sci Sports Exerc. 2013;45(4):714-21. doi:10.1249/MSS.0b013e318279707a.

63. Ortega FB, Silventoinen K, Tynelius P et al. Muscular strength in male adolescents and premature death: Cohort study of one million participants. Br Med J. 2012;345(7884).

64. Barnekow-Bergkvist M, Hedberg GE, Janlert U et al. Determinants of self-reported neck-shoulder and low back symptoms in a general population. Spine. 1998;23(2):235-43. doi:10.1097/00007632-199801150-00017.

65. Mikkelsson LO, Nupponen H, Kaprio J et al. Adolescent flexibility, endurance strength, and physical activity as predictors of adult tension neck, low back pain, and knee injury: a 25 year follow up study. Br J Sports Med. 2006;40(2):107-13.

66. Sjölie AN, Ljunggren AE. The significance of high lumbar mobility and low lumbar strength for current and future low back pain in adolescents. Spine. 2001;26(23):2629-36.

67. Harter S. Manual for the self-perception profile for adolescents. University of Denver; 1988.

68. Whitehead JR. A study of children's physical self-perceptions using an adapted physical self-perception profile questionnaire. Pediatr Exerc Sci. 1995;7:132-.

69. Haugen T, Ommundsen Y, Seiler S. The relationship between physical activity and physical self-esteem in adolescents: The role of physical fitness indices. Pediatr Exerc Sci. 2013;25(1):138-53.

70. Morano M, Colella D, Robazza C et al. Physical self-perception and motor performance in normal-weight, overweight and obese children. Scand J Med Sci Sports. 2011;21(3):465-73.

71. Marsh HW. Construct validity of physical self-description questionnaire responses: Relations to external criteria. J Sport Exerc Psychol. 1996;18:111-31.

72. Lubans DR, Cliff DP. Muscular fitness, body composition and physical self-perception in adolescents. J Sci Med Sport. 2011;14(3):216-21. doi:http://dx.doi.org/10.1016/j.jsams.2010.10.003.

73. Smith AJ, O'Sullivan PB, Campbell AC et al. The relationship between back muscle endurance and physical, lifestyle, and psychological factors in adolescents. J Orthop Sports Phys Ther. 2010;40(8):517-23. doi:http://dx.doi.org/10.2519/jospt.2010.3369.

74. Hasselstrom H, Hansen SE, Froberg K et al. Physical fitness and physical activity during adolescence as predictors of cardiovascular disease risk in young adulthood. Danish Youth and Sports study. An eight-year follow-up study. Int J Sports Med. 2002;23(1):S27-S31.

75. Janz KF, Dawson JD, Mahoney LT. Increases in physical fitness during childhood improve cardiovascular health during adolescence: the Muscatine Study. Int J Sports Med. 2002;23 Suppl 1:S15-S21.

76. Freitas D, Beunen G, Maia J et al. Tracking of fatness during childhood, adolescence and young adulthood: a 7-year follow-up study in Madeira Island, Portugal. Ann Hum Biol. 2012;39(1):59-67.

77. Hruby A, Chomitz VR, Arsenault LN et al. Predicting maintenance or achievement of healthy weight in children: The impact of changes in physical fitness. Obesity. 2012;20(8):1710-7. doi:http://dx.doi.org/10.1038/oby.2012.13.

78. Hill JO. Understanding and addressing the epidemic of obesity: an energy balance perspective. Endocr Rev. 2006;27(7):750-61.

79. Bouchard C, Blair SN, Haskell WL. Physical activity and health. 2 ed. Champaigne, IL: Human Kinetics; 2012.

80. Castelli DM, Valley JA. Chapter 3: The Relationship of Physical Fitness and Motor Competence to Physical Activity. J Teach Phys Educ. 2007;26(4):358-74.

81. Fogelholm M, Stigman S, Huisman T et al. Physical fitness in adolescents with normal weight and overweight. Scand J Med Sci Sports. 2008;18(2):162-70. doi:10.1111/j.1600-0838.2007.00685.x.

82. Deforche B, Lefevre J, De Bourdeaudhuij I et al. Physical fitness and physical activity in obese and nonobese Flemish youth. Obes Res. 2003;11(3):434-41.

83. Artero EG, España-Romero V, Ortega FB et al. Health-related fitness in adolescents: Underweight, and not only overweight, as an influencing factor. The AVENA study. Scand J Med Sci Sports. 2010;20(3):418-27. doi:10.1111/j.1600-0838.2009.00959.x.

84. Milliken LA, Faigenbaum AD, Loud RL et al. Correlates of upper and lower body muscular strength in children. J Strength Cond Res. 2008;22(4):1339-46.

85. Rizzoli R, Bianchi ML, Garabédian M et al. Maximizing bone mineral mass gain during growth for the prevention of fractures in the adolescents and the elderly. Bone. 2010;46(2):294-305.

86. Eisman J, Kelly P, Morrison N et al. Peak bone mass and osteoporosis prevention. Osteoporos Int. 1993;3(1):56-60.

87. Clark EM, Ness AR, Bishop NJ et al. Association between bone mass and fractures in children: a prospective cohort study. J Bone Miner Res. 2006;21(9):1489-95.

88. Kelly P, Eisman J, Sambrook P. Interaction of genetic and environmental influences on peak bone density. Osteoporos Int. 1990;1(1):56-60.

89. Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I et al. Enhanced bone mass and physical fitness in prepubescent footballers. Bone. 2003;33(5):853-9.

90. Vicente-Rodriguez G, Dorado C, Perez-Gomez J et al. Enhanced bone mass and physical fitness in young female handball players. Bone. 2004;35(5):1208-15.

91. Babaroutsi E, Magkos F, Manios Y et al. Body mass index, calcium intake, and physical activity affect calcaneal ultrasound in healthy Greek males in an age-dependent and parameter-specific manner. J Bone Miner Metab. 2005;23(2):157-66.

92. Pollitzer WS, Anderson JJ. Ethnic and genetic differences in bone mass: a review with a hereditary vs environmental perspective. Am J Clin Nutr. 1989;50(6):1244-59.

93. Gilsanz V, Roe TF, Mora S et al. Changes in vertebral bone density in black girls and white girls during childhood and puberty. N Engl J Med. 1991;325(23):1597-600.

94. Foo LH, Zhang Q, Zhu K et al. Influence of body composition, muscle strength, diet and physical activity on total body and forearm mass in Chinese adolescent girls. Br J Nutr. 2007;98:1281-7.

95. Vicente-Rodríguez G. How does exercise affect bone development during growth? Sports Med. 2006;36(7):561-9.

96. Srinivasan SR, Berenson GS. Childhood lipoprotein profiles and implications for adult coronary artery disease: The Bogalusa Heart Study. Am J Med Sci. 1995;310(6):S68.

97. McGill HC, McMahan CA, Zieske AW et al. Association of coronary heart disease risk factors with microscopic qualities of coronary atherosclerosis in youth. Circulation. 2000;102(4):374-9.

98. Kemper HC, Snel J, Verschuur R et al. Tracking of health and risk indicators of cardiovascular diseases from teenager to adult: Amsterdam Growth and Health Study. Prev Med. 1990;19(6):642-55.

99. Mota J, Vale S, Martins C et al. Influence of muscle fitness test performance on metabolic risk factors among adolescent girls. Diabetol Metab Syndr. 2010;2(42):1-7. doi:10.1186/1758-5996-2-42.

100. Eisenmann JC, Welk GJ, Wickel EE et al. Combined influence of cardiorespiratory fitness and body mass index on cardiovascular disease risk factors among 8-18 year old youth: The Aerobics Center Longitudinal Study. Int J Pediatr Obes. 2007;2(2):66-72.

101. Gutin B, Yin Z, Humphries MC et al. Relations of body fatness and cardiovascular fitness to lipid profile in black and white adolescents. Pediatr Res. 2005;58(1):78-82.

102. Schranz N, Tomkinson G, Olds T. What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A systematic review and meta-analysis. Sports Med. 2013;43(9):893-907.

103. Shaibi GQ, Cruz ML, Ball GD et al. Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. Med Sci Sports Exerc. 2006;38(7):1208-15.

104. McGuigan MR, Tatasciore M, Newton RU et al. Eight weeks of resistance training can significantly alter body composition in children who are overweight or obese. J Strength Cond Res. 2009;23(1):80-5.

105. Leboeuf-Yde C, Kyvik KO. At what age does low back pain become a common problem?: A study of 29,424 individuals aged 12 – 41 years. Spine. 1998;23(2):228-34.

106. Harreby M, Kjer J, Hesselsøe G et al. Epidemiological aspects and risk factors for low back pain in 38-year-old men and women: a 25-year prospective cohort study of 640 school children. Eur Spine J. 1996;5(5):312-8.

107. King S, Chambers CT, Huguet A et al. The epidemiology of chronic pain in children and adolescents revisited: A systematic review. Pain. 2011;152(12):2729-38. doi:http://dx.doi.org/10.1016/j.pain.2011.07.016.

108. Newcomer K, Sinaki M. Low back pain and its relationship to back strength and physical activity in children. Acta Paediatr. 1996;85(12):1433-9.

109. Perry M, Straker L, O'Sullivan P et al. Fitness, motor competence, and body composition are weakly associated with adolescent back pain. J Orthop Sports Phys Ther. 2009;39(6):439-49.

110. Cardon G, De Bourdeaudhuij I, De Clercq D et al. Physical fitness, physical activity, and self-reported back and neck pain in elementary schoolchildren. Pediatr Exerc Sci. 2004;16(2):147-57.

111. Viner R, Booy R. ABC of adolescence: Epidemiology of health and illness. Br Med J. 2005;330(7488):411-4.

112. Biddle SJ, Mutrie N. Psychology of physical activity: Determinants, well-being and interventions. 2nd ed. Abingdon, OX: Routledge; 2008.

113. Fox KR. Self-esteem, self-perceptions and exercise. Int J Sport Psychol. 2000;31(2):228-40.

114. Harter S. Manual for the self-perception profile for children. University of Denver; 1985.

115. Stodden DF, Goodway JD, Langendorfer SJ et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. Quest. 2008;60(2):290-306.

116. Biddle SJ, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. Br J Sports Med. 2011;45(11):886-95.

117. Dwyer T, Sallis JF, Blizzard L et al. Relation of academic performance to physical activity and fitness in children Pediatr Exerc Sci. 2001;13(3):225-37.

118. Du Toit D, Pienaar AE, Truter L. Relationship between physical fitness and academic performance in South African children. S Afr J Res Sport Ph. 2011;33(3):23-35.

119. Edwards JU, Mauch L, Winkelman MR. Relationship of nutrition and physical activity behaviors and fitness measures to academic performance for sixth graders in a midwest city school district. J Sch Health. 2011;81(2):65-73. doi:10.1111/j.1746-1561.2010.00562.x.

120. Castelli DM, Hillman CH, Buck SM et al. Physical fitness and academic achievement in third- and fifth-grade students. J Sport Exerc Psychol. 2007;29(2):239-52.

121. Ruiz JR, Ortega FB, Castillo R et al. Physical activity, fitness, weight status, and cognitive performance in adolescents. J Pediatr. 2010;157(6):917-22. doi:10.1016/j.jpeds.2010.06.026.

122. Hillman CH, Castelli DM, Buck SM. Aerobic fitness and neurocognitive function in healthy preadolescent children. Med Sci Sports Exerc. 2005;37(11):1967-74.

123. Coe DP, Pivarnik JM, Womack CJ et al. Effect of physical education and activity levels on academic achievement in children. Med Sci Sports Exerc. 2006;38(8):1515-9.

124. Cotman CW, Berchtold NC. Exercise: a behavioral intervention to enhance brain health and plasticity. Trends Neurosci. 2002;25(6):295-301.

125. Hillman CH, Buck SM, Themanson JR et al. Aerobic fitness and cognitive development: Event-related brain potential and task performance indices of executive control in preadolescent children. Dev Psychol. 2009;45(1):114-29.

126. Bloemers F, Collard D, Paw MCA et al. Physical inactivity is a risk factor for physical activity-related injuries in children. Br J Sports Med. 2012;46(9):669-74.

127. Schwingshandl J, Sudi K, Eibl B et al. Effect of an individualised training programme during weight reduction on body composition: a randomised trial. Arch Dis Child. 1999;81(5):426-8.

128. Watts K, Beye P, Siafarikas A et al. Exercise training normalizes vascular dysfunction and improves central adiposity in obese adolescents. J Am Coll Cardiol. 2004;43(10):1823-7.

129. Velez A, Golem DL, Arent SM. The impact of a 12-week resistance training program on strength, body composition, and self-concept of Hispanic adolescents. J Strength Cond Res. 2010;24(4):1065-73.

130. Woods JA, Pate RR, Burgess ML. Correlates to performance on field tests of muscular strength. Pediatr Exerc Sci. 1992;4(4):302-11.

131. Almuzaini KS. Muscle function in Saudi children and adolescents: Relationship to anthropometric characteristics during growth. Pediatr Exerc Sci. 2007;19(3):319-33.

132. Annesi JJ, Pierce LL, Bonaparte WA et al. Preliminary effects of the Youth Fit For Life protocol on body mass index in Mexican American children in YMCA before- and after-school care programs. Hisp Health Care Int. 2009;7(3):123-9. doi:10.1891/1540-4153.7.3.123.

133. Ara I, Vicente-Rodriguez G, Jimenez-Ramirez J et al. Regular participation in sports is associated with enhanced physical fitness and lower fat mass in prepubertal boys. Int J Obes. 2004;28(12):1585-93. doi:http://dx.doi.org/10.1038/sj.ijo.0802754.

134. Bovet P, Auguste R, Burdette H. Strong inverse association between physical fitness and overweight in adolescents: a large school-based survey. Int J Behav Nutr Phys Act. 2007;4:24-8. doi:10.1186/1479-5868-4-24.

135. Brunet M, Chaput JP, Tremblay A. The association between low physical fitness and high body mass index or waist circumference is increasing with age in children: the ‘Québec en Forme’ Project. Int J Obes. 2007;31(4):637-43. doi:10.1038/sj.ijo.0803448.

136. Butterfield SA, Lehnhard RA, Coladarci T. Age, sex, and body mass index in performance of selected locomotor and fitness tasks by children in grades K-2. Percept Mot Skills. 2002;94(1):80-6.

137. Castro-Piñero J, González-Montesinos JL, Mora J et al. Percentile values for muscular strength field tests in children aged 6 to 17 years: Influence of weight status. J Strength Cond Res. 2009;23(8):2295-310.

138. Chen LJ, Fox KR, Haase A et al. Obesity, fitness and health in Taiwanese children and adolescents. Eur J Clin Nutr. 2006;60(12):1367-75. doi:10.1038/sj.ejcn.1602466.

139. Chen W, Lin CC, Peng CT et al. Approaching healthy body mass index norms for children and adolescents from health-related physical fitness. Obes Rev. 2002;3(3):225-32. doi:10.1046/j.1467-789X.2002.00064.x.

140. Cureton KJ, Boileau RA, Lohman Tg. Relationship between body composition measures and AAHPER test performances in young boys. Res Q. 1975;46(2):218-29.

141. Gonzalez-Suarez CB, Caralipio N, Gambito E et al. The association of physical fitness with body mass index and waist circumference in Filipino preadolescents. Asia Pac J Public Health. 2013;25(1):74-83. doi:http://dx.doi.org/10.1177/1010539511412764.

142. Gonzalez-Suarez CB, Grimmer-Somers K. The association of physical activity and physical fitness with pre-adolescent obesity: an observational study in Metromanila, Philippines. J Phys Act Health. 2011;8(6):804-10.

143. Heroux M, Onywera V, Tremblay MS et al. The relation between aerobic fitness, muscular fitness, and obesity in children from three countries at different stages of the physical activity transition. ISRN Obesity. 2013;2013. doi:10.1155/2013/134835.

144. Huang YC, Malina RM. Body mass index and individual physical fitness tests in Taiwanese youth aged 9-18 years. Int J Pediatr Obes. 2010;5(5):404-11. doi:10.3109/17477160903497902.

145. Huberty JL, Rosenkranz RR, Balluff MA et al. Describing weight status and fitness in a community sample of children attending after-school programming. J Sports Med Phys Fitness. 2010;50(2):217-28.

146. Joshi P, Bryan C, Howat H. Relationship of body mass index and fitness levels among schoolchildren. J Strength Cond Res. 2012;26(4):1006-14. doi:10.1519/JSC.0b013e31822dd3ac.

147. Lloyd LK, Bishop PA, Walker JL et al. The influence of body size and composition on FITNESSGRAM test performance and the adjustment of FITNESSGRAM test scores for skinfold thickness in youth. Meas Phys Educ Exerc Sci. 2003;7(4):205-26.

148. Malina RM, Beunen GP, Classens AL et al. Fatness and physical fitness of girls 7 to 17 years. Obes Res. 1995;3(3):221-31.

149. Malina RM, Reyes MEP, Tan SK et al. Physical fitness of normal, stunted and overweight children 6-13 years in Oaxaca, Mexico. Eur J Clin Nutr. 2011;65(7):826-34. doi:10.1038/ejcn.2011.44.

150. Minck MR, Ruiter LM, W. VM et al. Physical fitness, body fatness, and physical activity: The Amsterdam Growth and Health Study. Am J Hum Biol. 2000;12:593-9.

151. Pate RR, Slentz CA, Katz DP. Relationships between skinfold thickness and performance of health related fitness test items. Res Q Exerc Sport. 1989;60(2):183-9.

152. Pino-Ortega J, De la Cruz-Sanchez E, Martinez-Santos R. Health-related fitness in school children: compliance with physical activity recommendations and its relationship with body mass index and diet quality. Arch Latinoam Nutr. 2010;60(4):374-9.

153. Pissanos BW, Moore JB, Reeve TG. Age, sex, and body composition as predictors of children's performance on basic motor abilities and health-related fitness items. Percept Mot Skills. 1983;56(1):71-7.

154. Pongprapai S, Mo-suwan L, Leelasamran W. Physical fitness of obese school children in Hat Yai, southern Thailand. Se Asian J Trop Med. 1994;25(2):354-60.

155. Sacchetti R, Ceciliani A, Garulli A et al. Physical fitness of primary school children in relation to overweight prevalence and physical activity habits. J Sports Sci. 2012;30(7):633-40. doi:http://dx.doi.org/10.1080/02640414.2012.661070.

156. Slaughter MH, Lohman TG, Misner JE. Relationship of somatotype and body composition to physical performance in 7- to 12- year old boys. Res Q. 1977;48(1):159-68.

157. Tokmakidis SP, Kasambalis A, Christodoulos AD. Fitness levels of Greek primary schoolchildren in relationship to overweight and obesity. Eur J Pediatr. 2006;165(12):867-74. doi:10.1007/s00431-006-0176-2.

158. Ara I, Moreno LA, Leiva MT et al. Adiposity, physical activity, and physical fitness among children from Aragón, Spain. Obesity. 2007;15(8):1918-24. doi:10.1038/oby.2007.228.

159. Huotari PRT, Nupponen H, Laakso L et al. Secular trends in muscular fitness among Finnish adolescents. Scand J Public Health. 2010;38(7):739-47. doi:10.1177/1403494810384425.

160. Raudsepp L, Jurimae T. Relationships between somatic variables, physical activity, fitness and fundamental motor skills in prepubertal boys. Biol Sport. 1996;13(4):279-89.

161. Grund A, Dilba B, Forberger K et al. Relationships between physical activity, physical fitness, muscle strength and nutritional state in 5- to 11-year-old children. Eur J Appl Physiol. 2000;82(5-6):425-38. doi:10.1007/s004210000197.

162. Kim J, Must A, Fitzmaurice GM et al. Relationship of physical fitness to prevalence and incidence of overweight among schoolchildren. Obes Res. 2005;13(7):1246-54.

163. Raudsepp L, Jurimae T. Physical activity, fitness, and adiposity of prepubertal girls. Pediatr Exerc Sci. 1996;8(3):259-67.

164. Slaughter MH, Lohman TG, Misner JE. Association of somatotype and body composition to physical performance in 7-12 year-old-girls. J Sports Med Phys Fitness. 1980;20(2):189-98.

165. Andersen LB. Changes in physical activity are reflected in changes in fitness during late adolescence: a 2-year follow-up study. J Sports Med Phys Fitness. 1994;34(4):390-7.

166. Benson AC, Torode ME, Fiatarone Singh MA. The effect of high-intensity progressive resistance training on adiposity in children: A randomized controlled trial. Int J Obes. 2008;32(6):1016-27. doi:10.1038/ijo.2008.5.

167. Afghani A, Xie B, Wiswell RA et al. Bone mass of asian adolescents in China: influence of physical activity and smoking. Med Sci Sports Exerc. 2003;35(5):720-9. doi:10.1249/01.mss.0000064940.76574.bd.

168. Cheng JCY, Leung SSSF, Lee WTK et al. Determinants of axial and peripheral bone mass in Chinese adolescents. Arch Dis Child. 1998;78:524-30.

169. Fonseca RMC, De Franca NM, Van Praagh E. Relationship between indicators of fitness and bone density in adolescent Brazilian children. Pediatr Exerc Sci. 2008;20(1):40-9.

170. Ginty F, Rennie KL, Mills L et al. Positive, site-specific associations between bone mineral status, fitness, and time spent at high-impact activities in 16- to 18-year-old boys. Bone. 2005;36(1):101-10. doi:10.1016/j.bone.2004.10.001.

171. Gracia-Marco L, Vicente-Rodríguez G, Casajús J et al. Effect of fitness and physical activity on bone mass in adolescents: the HELENA Study. Eur J Appl Physiol. 2011;111(11):2671-80.

172. Kardinaal AF, Hoorneman G, Väänänen K et al. Determinants of bone mass and bone geometry in adolescent and young adult women. Calcif Tissue Int. 2000;66(2):81-9.

173. van Langendonck L, Claessensy AL, Lysensz R et al. Association between bone, body composition and strength in premenarcheal girls and postmenopausal women. Ann Hum Biol. 2004;31(2):228-44.

174. Duppe H, Gardsell P, Johnell O et al. Bone mineral density, muscle strength and physical activity: A population-based study of 332 subjects aged 15-42 years. Acta Orthop Scand. 1997;68(2):97-103.

175. Rice S, Blimkie CJR, Webber CE et al. Correlates and determinants of bone mineral content and density in healthy adolescent girls. Can J Physiol Pharmacol. 1993;71(12):923-30.

176. Witzke KA, Snow CM. Lean body mass and leg power best predict bone mineral density in adolescent girls. Med Sci Sports Exerc. 1999;31(11):1558-63.

177. García-Artero E, Ortega FB, Ruiz JR et al. Lipid and metabolic profiles in adolescents are affected more by physical fitness than physical activity (AVENA study). Rev Esp Cardiol. 2007;60(6):581-8.

178. Magnussen C, Schmidt M, Dwyer T et al. Muscular fitness and clustered cardiovascular disease risk in Australian youth. Eur J Appl Physiol. 2012;112(8):3167-71.

179. Ortega FB, Ruiz JR, Castillo MJ et al. Low level of physical fitness in Spanish adolescents. Relevance for future cardiovascular health (AVENA study). Rev Esp Cardiol. 2005;58(8):898-909.

180. Thorsen K, Nordstrom P, Lorentzon R et al. The relation between bone mineral density, insulin-like growth factor I, lipoprotein (a), body composition, and muscle strength in adolescent males. J Clin Endocrinol Metab. 1999;84(9):3025-9.

181. Barnekow-Bergkvist M, Hedberg G, Janlert U et al. Adolescent determinants of cardiovascular risk factors in adult men and women. Scand J Public Health. 2001;29(3):208-17.

182. Brandon LJ, Fillingim J. Health fitness training responses of normotensive and elevated normotensive children. Am J Health Promot. 1990;5(1):30-5.

183. Hoekstra T, Boreham CA, Murray LJ et al. Associations between aerobic and muscular fitness and cardiovascular disease risk: The Northern Ireland young hearts study. J Phys Act Health. 2008;5(6):815-29.

184. Andersen L, Wedderkopp N, Leboeuf-Yde C. Association between back pain and physical fitness in adolescents. Spine. 2006;31(15):1740-4. doi:10.1097/01.brs.0000224186.68017.e0.

185. Johnson OE, Mbada CE, Agbeja OB et al. Relationship between physical activity and back extensor muscles' endurance to the risk of low-back pain in school-aged adolescents. TAF Prev Med Bull. 2011;10(4):415-20.

186. Johnson OE, Mbada CE, Akosile CO et al. Isometric endurance of the back extensors in school-aged adolescents with and without low back pain. J Back Musculoskelet Rehabil. 2009;22(4):205-11. doi:10.3233/bmr-2009-0.

187. Mafanya C, Rhoda A. Predictors of neck pain among South African youth. Af J Phys Health Educ Rec Dan. 2011:82-9.

188. O'Sullivan PB, Smith AJ, Beales DJ et al. Association of biopsychosocial factors with degree of slump in sitting posture and self-report of back pain in adolescents: a cross-sectional study. Phys Ther. 2011;91(4):470-83. doi:10.2522/ptj.20100160.

189. Salminen JJ, Maki P, Oksanen A et al. Spinal mobility and trunk muscle strength in 15-year-old schoolchildren with and without low-back pain. Spine. 1992;17(4):405-11.

190. Feldman DE, Shrier I, Rossignol M et al. Risk factors for the development of low back pain in adolescence. Int J Epidemiol. 2000;154:30-6.

191. Salminen JJ, Erkintalo M, Laine M et al. Low back pain in the young. A prospective three-year follow-up study of subjects with and without low back pain. Spine. 1995;20(19):2101-7.

192. Hands B, Larkin D, Parker H et al. The relationship among physical activity, motor competence and health-related fitness in 14-year-old adolescents. Scand J Med Sci Sports. 2009;19(5):655-63. doi:10.1111/j.1600-0838.2008.00847.x.

193. Sallis JF, McKenzie TL, Alcaraz JE. Habitual physical activity and health-related physical fitness in fourth-grade children. Am J Dis Child. 1993;147(8):890-6.

194. Salminen JJ, Oksanen A, Maki P et al. Leisure time physical activity in the young. Correlation with low-back pain, spinal mobility and trunk muscle strength in 15-year-old school children. Int J Sports Med. 1993;14(7):406-10.

Table 1. Summary of studies examining the association between health benefits and muscular fitness

Benefits	Associated with MF	Not associated with MF	Summary coding	
	references	references	n/N[a] for benefit (%)	association (+/-)[b]
Physiological benefits				
Adiposity				
Total	[131-133, 83, 134-140, 82, 81, 76, 141-143, 77, 144-150, 50, 151-157, 130, 158-160, 60, 70, 39, 74, 75, 99]	[161-165]	43/48 (90)	- -
Central	[135, 76, 143, 50, 158, 56, 74, 75, 99, 57]	[166, 161, 60, 39]	10/14 (71)	- -
Bone health	[167, 168, 51, 169, 94, 170-173, 33, 53, 54]	[52, 174, 175, 55, 176]	12/17 (71)	++
CVD and metabolic risk factors	[56, 32, 177, 39, 178, 59, 60, 99, 179, 57, 62, 180, 58, 61, 30]	[181, 182, 74, 183, 75]	15/20 (75)	- -
Musculoskeletal pain	[64, 184-188, 109, 189, 66]	[110, 190, 65, 108, 191, 73]	9/15 (60)	?
Psychological and cognitive benefits				
Self-esteem	[69, 72, 71, 70, 73]	[49]	5/6 (83)	++
Cognitive ability	[35, 118, 117]	[120, 119, 121]	3/6 (50)	?

Abbreviations: MF = muscular fitness; CVD = cardiovascular disease

[a] n/N = number of studies reporting a statistically significant finding/ total number of studies reporting on the benefit

[b] ++ = strong evidence of a positive association; - - = strong evidence of an inverse association; ? = inconsistent/uncertain

Electronic Supplementary Material, Table S1. Summary of included studies

Study	Sample; age (SD); sex (M/F); location	Study design	Analyses	MF measure(s)	Benefits assessed	Findings
Afghani et al. [167]	n=466; 12-16 yrs; (300/166); China	Cross-sectional	Bivariate correlation	GS	Forearm and heel BMD and BMC	There were significant moderate correlations between grip strength and forearm and heel BMC and BMD.
Almuzaini [145]	n=44; 11-19 yrs; (44/0); Saudi Arabia	Cross-sectional	Bivariate correlation	GS; Isokinetic strength and endurance (knee flexors and extensors); VJ	BMI; Sum of 4 skinfolds; %BF	BMI was positively associated with GS, Isokinetic strength and VJ. Sum of 4 skinfolds was not associated with any MF measure. %BF was negatively associated with VJ.
Andersen [165]	n=259; 16.5(0.6) yrs at baseline; (117/142); Denmark	Longitudinal (2 year follow-up)	Stepwise multiple regression	Biceps curls; Sit ups; Back extension CMJ; Seated ball throw (iron ball)	BMI	Change in BMI was associated with change in back extension. All other relationships were non-significant.
Andersen [184]	n=9413; 17.1(0.6) yrs; (3956/5457); Denmark	Cross-sectional	Logistic regression	BME (Biering-Sørensen test); VJ	Back pain (Self-reported)	VJ was not associated with back pain. BME was inversely associated with back pain after adjustment for height and sex. OR's for back pain were 0.89 (95% CI, 0.78–1.02), 0.78 (95% CI, 0.68–0.89), and 0.71 (95% CI, 0.62–0.82) for the upper three quartiles compared with the lowest quartile of BME, respectively. The highest quartile of BME had 20% lower risk of back pain compared with the lowest quartile.

Annesi [132]	n=25; 5-11 yrs; (17/8); USA	Experimental (12 weeks)	Multiple linear regression	1 minute push ups	BMI	A unique contribution to the overall variance in BMI was made by change scores in muscular strength but not changes in CRF.
Ara et al. [133]	n=114; 9.4 (1.5) yrs; (114/0); Spain	Cross-sectional	Bivariate correlation; Linear regression	Max isometric strength; squat jump; CMJ	%BF	%BF and total and regional fat mass were significantly associated with jump heights of the squat jump and CMJ and with maximal strength.
Ara et al. [158]	n= 1068; 7-12 yrs; NR; Spain	Cross-sectional	t-test; Bivariate correlation	GS; SLJ; Sit ups; BAH	Weight status (BMI); Sum of 6 skinfolds; Trunk skinfolds	Correlations between sum of 6 skinfolds, trunk skinfolds, BMI and BAH were moderate and positive.
Artero et al. [83]	n=2472; 13-18.5 yrs; (1196/1278); Spain	Cross-sectional	ANCOVA	GS, BAH; SLJ	Weight status (BMI)	Overweight and obese boys and girls had significantly better GS compared with underweight and normal weight. BAH and SLJ were significantly better for normal weight compared with overweight and obese. Associations may be related to differences in body composition.
Artero et al. [56]	n=709; 14.9(1.3) yrs; (346/363); Europe	Cross-sectional	Multiple linear regression; ANCOVA	Relative GS, SLJ; MFS	Clustered metabolic risk	MF was negatively associated with clustered risk independent of CRF (β=-0.249, p=<0.001). After adjustment for CRF, the odds of having high clustered risk in the lowest quartile compared with the highest quartile was 5.3. Significant differences in clustered risk between MF levels persisted among non-overweight and overweight participants.
Artero et al. [58]	n= 709; 14.9(1.3) yrs; (346/363); Europe	Cross-sectional	Partial correlation; ANCOVA;	Relative GS, SLJ; MFS	Clustered inflammation score	MF was significantly associated with the individual biomarkers and clustered inflammation score independent of CRF

			Multiple linear regression; Logistic regression			and insulin resistance (β range = -0.298 to -0.049). Adjustment for adiposity attenuated the associations. After adjustment for CRF and insulin resistance, the odds of having high clustered inflammation were significantly greater for those with low MF. Decreasing values of inflammatory score were observed across incremental levels of MF in both non-overweight and overweight adolescents (P<0.05).
Barnekow-Bergkvist et al. [64]	n=278; 16.1(0.3) yrs at baseline; (157/121); Sweden	Longitudinal (18 year follow-up)	Multiple logistic regression	Two hand lift; GS; Bench press	Experiencing lower back or neck/shoulder pain symptoms	High bench press performance during adolescence was associated with a significantly decreased risk of neck-shoulder problems in adulthood among men. High two-hand lift performance during adolescence was associated with a significantly decreased risk of low back problems in adulthood among women.
Barnekow-Bergkvist et al. [181]	n=278; 16.1(0.3) yrs at baseline; (157/121); Sweden	Longitudinal (18 year follow-up)	Bivariate relative risk; Multiple logistic regression.	Two hand lift; Sit ups; Bench press	BMI	Higher performance in the bench press was associated with greater odds of high BMI for males. Higher performance in the two-hand lift was associated with increased odds of high BMI for females but not males at age 34.
Barnekow-Bergkvist et al. [54]	n=36; 16.0(0.3) yrs; 15-17 years (at baseline); (0/36); Sweden	Longitudinal (20 year follow-up)	ANCOVA; Stepwise multiple regression	Hanging leg lift; GS; Two hand lift	Multiple-site BMD	MF during adolescence independently predicted BMD of the whole body, arms, legs and trochanter in adulthood.
Benson et al. [32]	n=126; 10-15 yrs; (71/55); New Zealand	Cross-sectional	Simple and Multiple stepwise	1RM bench press; 1RM leg press; Absolute	Insulin sensitivity (HOMA2-IR)	All strength variables were associated with insulin resistance. High and moderate strength groups were 98% less likely than

			regression; Logistic regression	and relative strength composite		the low strength group to have high insulin resistance. The association for the high strength group was slightly attenuated but persisted after adjustment for CRF. If relative strength was used in the model, the protective effect was no longer significant.
Benson et al. [166]	n=78; 12.3(1.3) yrs; (46/32); New Zealand	Experimental (8 week RCT)	Simple and Multiple stepwise regression	1RM bench press; 1RM leg press; Absolute and relative strength composite	WC	The decrease in WC of the whole cohort (INT and CON combined) over the study period was highest among those with higher relative upper body strength at baseline (r= 0.257, p= 0.036). The improvement in WC among the whole group was greatest in those with the greatest change in upper body absolute (r= -0.34, p= 0.006) and relative (r= -0.40, p= 0.001) strength. However, when separated by treatment group this association was only significant among control subjects and only for relative strength.
Bovet et al. [134]	n=4343; 12-15 yrs; (2202/2141); Seychelles	Cross-sectional	Locally weighted regression	Push ups; Sit ups; Lateral jump; VJ; Basketball throw	BMI	For all tests except the ball throw, healthy weight subjects performed better than overweight or obese subjects. There was a significantly higher proportion of healthy weight subjects performing above the 75th percentile compared with overweight/obese peers for the VJ, lateral jump, push ups and sit ups. In the basketball throw a higher proportion of obese subjects performed above the 75th percentile compared with healthy weight subjects.
Brandon & Fillingim	n=386; 9(0.9) yrs; (19/187); USA	Cross-sectional	Bivariate correlation	1 minute Sit ups	Elevated blood pressure (High BP ≥	There was a significant inverse association between systolic BP and Sit up

[182]					108/76)	performance among those with elevated BP. The same relationship was not significant among those with low BP, nor was the association between Sit ups and diastolic BP for either group.
Brunet et al. [135]	n=1140; 6-10 yrs; (591/549); Canada	Cross-sectional	Bivariate correlation; Partial correlation	1 minute Sit ups; SLJ	BMI; WC	BMI and WC, and MF were significantly inversely associated for both genders and these correlations were higher among older children.
Butterfield et al. [136]	n=65; 5-8 yrs; NR; USA	Cross-sectional	Multiple linear regression	GS; 1 minute Sit ups	BMI	BMI was significantly associated with GS (Beta= .27, p<.05) and significantly associated with Sit ups (Beta= - .26, p<.05)
Cardon et al. [110]	749; 8-12 yrs; (367/382); Belgium	Cross-sectional	ANOVA	GS; BAH; SLJ	Back and neck pain (Self reported)	There were no significant differences in performance on any of the MF tests between subjects experiencing pain and those not experiencing pain.
Castelli et al. [120]	n=259; 9.5(0.7) yrs; (132/127); USA	Cross-sectional	Bivariate correlation; Two step hierarchical regression	Fitnessgram: Push ups; Sit ups	Academic achievement (ISAT tests)	CRF and BMI were significant predictors of achievement across all three ISAT tests but Push ups and Sit ups performance were not.
Castelli & Valley [80]	n=230; 7-12 yrs; (140/90); USA	Cross-sectional	Bivariate correlation; Two-step hierarchical regression	Fitnessgram: Push ups; Sit ups	BMI	Push ups and Sit ups were inversely associated with BMI
Castro-Piñero et al.	n=2778; 6-17.9 yrs; (1513/1265); Spain	Cross-sectional	ANOVA	Push ups; BAH, Pull ups; Sit	Weight status (BMI)	Underweight and normal weight children scored significantly better than overweight

[137]				ups; Curl ups; SLJ; VJ; Basketball throw		and obese on the SLJ, VJ and Push ups for boys, and in the BAH for both boys and girls.
Chen et al. [138]	1999 sample: n=13,935; 6-18 yrs; (7,031/6904); Taiwan 2001 sample: n=24,586; 6-18 yrs; (12,367/12,219); Taiwan.	Cross-sectional	ANOVA	1 minute Sit ups	Weight status (BMI)	In both samples the normal weight group had significantly higher Sit ups performance compared with the overweight/obese group.
Chen et al. [139]	n=878,207; 7-18 yrs; (444,652/433,555); Taiwan	Cross-sectional	Simple relative risk	1 minute Sit ups; SLJ	Weight status (BMI)	The risk of poor MF (i.e., <25th percentile) was higher for overweight and obese subjects compared with normal weight subjects.
Cheng et al. [168]	n=179; 12-13 yrs; (92/87); China	Cross-sectional	Bivariate correlation; Stepwise multiple regression	GS; 1 minute Sit ups; VJ	Distal radius BMC; Spine BMD	Significant positive associations were found for both BMC and BMD and performance on all MF tests except for between BMC and Sit ups for boys and BMC and VJ for girls. VJ was a significant predictor of BMD in boys and Sit ups was a significant predictor of BMD in girls.
Cheng et al. [52]	n=179; 12-13 yrs; (92/87); China	Longitudinal (3 year follow-up)	Bivariate correlation; Stepwise multiple regression	GS; Knee flexion torque; 1 minute Sit ups; VJ	Distal radius BMC; Spine BMD	Mean score in the flexion test was significantly correlated with BMC and BMD in both genders in cross-sectional analyses. Longitudinally, peak flexion torque was a significant predictor of BMD for girls only.
Clark et al.	n=1590; 12-16yrs;	Cross-sectional	Logistic	GS; VJ	Bone fracture	Aerobically fit subjects were more likely to

[51]	(787/803); Northern Ireland		regression		(Parental report)	have had a fracture. GS and VJ moderated the CRF-fracture relationship such that the association existed for those with low GS and VJ but not for those with high GS and VJ. Compared to those in the high MF groups, those in the low MF groups had increased odds of having had a fracture.
Coe et al. [35]	n=312; 12.1(0.9) yrs; (162/150); USA	Cross-sectional	Bivariate correlation	Fitnessgram: Push ups; Sit ups	Yearly academic achievement; Terra Nova standardised test score; %BF	Push ups and Sit ups were weakly associated with grades and the Terra Nova test score. %BF was inversely associated with both Push ups and Sit ups.
Cureton et al. [140]	n=49; 8-11 yrs; (49/0); USA	Cross-sectional	Bivariate correlation; Multiple regression	Sit ups; Pull ups; SLJ	Body density (Hydrostatic weighing); Sum of 10 skinfolds; Sum of 2 skinfolds	Significant moderate inverse correlations were found between Pull ups and Sit ups and sum of 10 and sum of 2 skinfolds. Significant positive associations were found between body density and SLJ and Pull ups.
Deforche et al. [82]	n=3214; 12-18 yrs; NR; Belgium	Cross-sectional	ANOVA	GS; Sit ups; BAH; SLJ	Obesity (BMI over 90th percentile)	Non-obese subjects recorded significantly better performances in SLJ, Sit-ups and BAH. By contrast, obese subjects showed greater GS than the non-obese subjects.
Du Toit et al. [118]	n=212; 9-12 yrs; (94/118); South Africa	Cross-sectional	Bivariate correlation; Stepwise discriminant analysis	Total strength composite (from 5 MF tests)	Average of academic marks (eight core subjects)	Significant weak to moderate correlations were found between MF and academic performance. These were more consistent for girls and those in the 11- and 12-year age groups. Wall sitting, sit and reach, and Sit ups discriminated most between high and low achievers but this was not significant.
Duppe et al.	n=102; 15-16 yrs;	Cross-sectional	Bivariate	Isokinetic	Multiple site BMD	A positive correlation was found between

[174]	(58/44); Sweden		correlation; Partial correlation	strength (quadriceps)	and BMC	strength and BMD at almost all measured sites in boys. In girls the relationship was seen only between muscle strength and total body BMD. Adjustment for age and weight showed that strength was not an independent predictor of BMD at any site, in either sex.
Dwyer et al. [117]	n=7961; 7-15 yrs; NR; Australia	Cross-sectional	Bivariate correlation; Linear regression	GS, Flexion and extension strength (shoulder and leg); Push ups; Sit ups; SLJ	Scholastic ability (rated by school principal on a 5-point scale)	Boys and girls with a higher scholastic rating performed better in the Sit ups and SLJ in most age groups, shown by weak but consistent significant associations. Regression analysis showed that Sit ups performance was a significant predictor of scholastic ability even after adjustment for BMI, Parental involvement measures and SES.
Edwards et al. [119]	n=800; 11-13 yrs; NR; USA	Cross-sectional	ANOVA	Fitnessgram: Push ups; Pull ups	MAP test scores (Maths and reading ability level)	There were no significant differences in reading or maths test scores between those in the HFZ or the NIZ for Push ups or Pull ups, although it was borderline significant for Maths score and push ups.
Feldman et al. [190]	n=502; 13.8(0.1) yrs; (264/238); Canada	Longitudinal (6- and 12-month follow-up).	Multiple logistic regression	Isometric abdominal strength	Low back pain (Self-reported)	There was no significant difference in abdominal strength between those with and without back pain at either follow-up period. Logistic regression analysis determined that abdominal strength was not associated with back pain at 6- or 12-months.
Fogelholm et al. [81]	n=2348; 15-16 yrs; (1167/1181); Finland	Cross-sectional	Two-way ANOVA; Linear	Sit ups; 5-jump test	Weight status (BMI): (weight/height self reported)	Overweight and obese subjects performed poorer than their normal weight peers irrespective of PA level. Results of the

			regression			regression analysis indicated that weight status (unadjusted for PA) was a significant predictor of performance in the Sit ups and in the 5-jump.
Fonseca et al. [169]	n=144; 15-18 yrs; (65/79); Brazil	Cross-sectional	Bivariate correlation; Stepwise multiple regression	1 minute Sit ups; 1 minute Push ups	Multiple site BMD	Significant associations were found for Push ups and BMD among females but not males. Sit ups were associated with BMD at all sites among males but not females. Lean body mass and Sit ups significantly predicted total body BMD (b= 0.338, $p<0.01$, R^2 = 43%) for males but not females. Sit-ups were not predictive of BMD of the lumbar spine for either sex.
Foo et al. [94]	n=283; 15(0.5) yrs; (0/283); China	Cross-sectional	ANOVA; Multiple regression	GS	Total body and forearm BMC and bone area	GS was a significant independent predictor of proximal forearm BMC. GS was not a predictor of either total body or distal forearm BMC. GS was also a significant independent predictor of bone area of both the distal forearm and proximal forearm but not of the total body.
Freitas et al. [76]	n=450; 8-16 yrs at baseline; (231/219); Portugal	Longitudinal (7 year follow-up)	Stepwise multiple linear regression	Eurofit: GS; Sit ups; BAH; SLJ	Overweight/obesity (BMI, Sum of 5 skinfolds, and WC)	MF at baseline among the three age groups was predictive of adiposity 7 years later. Sit ups, GS and SLJ were significant predictors of adiposity among boys and BAH and SLJ were significant predictors among girls. The variance explained by MF was generally small ranging from 1 - 4% for males and 1 - 28% for girls across all age groups.
García-Artero et	n=460; 15.2(1.4); (248/212); Spain	Cross-sectional	Partial correlation;	Eurofit: GS; BAH; SLJ; GSI	Lipid-metabolic index	Polynomial contrast showed a linear relationship between the GSI and lipid-

al. [177]			Polynomial contrast; ANCOVA			metabolic index among females after adjusting for age, maturation, and CRF. A significant difference in lipid metabolic index between the first and third tertile of GSI was observed among females but not males.
Ginty et al. [170]	n=128; 16.8(0.5) yrs; (128/0); UK	Cross-sectional	Bivariate correlation; multiple linear regression	Back strength; GS	Multiple site BMC, BMD and BA	Back strength but not GS was significantly associated with time spent on high impact physical activities. GS was associated with BMC, BMD, and bone area at all measured sites. After size adjustment GS was only related to radius and trochanter BMC. Back strength was associated with BMC, BMD, and bone area at all measured sites. After size adjustment back strength was only related to BMC at multiple sites.
Gonzalez-Suarez & Grimmer-Somers [142]	n=380; 11-12 yrs; (167/213); Philippines	Cross-sectional	Kruskall-Wallis test; Bivariate correlation; Logistic regression	SLJ	Weight status (BMI)	Normal weight subjects performed significantly better than overweight and obese subjects in the SLJ. Overweight and obese subjects, adjusted for age and gender, were significantly more likely to perform below the median in the SLJ compared with normal weight subjects.
Gonzalez-Suarez et al. [141]	n=1021; 11.1(0.9); (513/508); Philippines	Cross-sectional	Bivariate correlation; ANOVA	1 minute Sit ups; SLJ	Weight status (BMI); WC	Obese boys and girls performed worse than normal weight and overweight in both the Sit ups and SLJ. Overweight and obese subjects were more likely than normal weight subjects to perform below the median in the SLJ and Sit ups, with the exception of overweight girls in the Sit ups. There were significant weak inverse correlations between BMI and WC and

						both Sit ups and SLJ for all subjects. Associations were stronger for males.
Gracia-Marco et al. [171]	n=390; 14.8(1.2); (182/191); Spain	Cross-sectional	ANCOVA	GS; SLJ	Multiple site BMC	Non-active adolescents performing worse in GS and SLJ had lower BMC. Non-active adolescents with better SLJ (tertile 3) showed higher whole body BMC than active ones in this tertile. Active adolescents with the worst GS showed higher BMC in the whole body and lower limbs than non-active adolescents.
Grøntved et al. [39]	n=332; 15.6(0.4) yrs at baseline; NR; Denmark	Longitudinal (6- and 12-yr follow-up)	Multiple linear regression; Multiple logistic regression	Relative isometric strength	Individual CVD risk factors and combined CVD risk score	Strength in youth was significantly associated with individual risk factors and the combined CVD risk score in young adulthood (adjusted for age, sex, recruitment period, and CRF). In multivariable-adjusted analyses including CRF, each 1 SD increase of isometric muscle strength in youth was associated with 0.59 lower odds of general overweight or obesity in young adulthood.
Grund et al. [161]	n=88; 5-11 yrs; (49/39); Germany	Cross-sectional	ANOVA; Bivariate correlation	Isometric strength of the quadriceps and Ischiocruralis	Weight status (BMI); Skinfolds	There were no significant differences in nutritional state between strength groups among the whole group. However, for older children the weakest group had higher BMI and skinfolds when compared with strongest group.
Hands et al. [192]	n=1585; 14.1(0.2) yrs; (814/771); Australia	Cross-sectional	Bivariate correlation; t-test; Multiple regression	Sit ups; Seated chest pass	BMI	BMI was weakly associated with chest pass and Sit ups among both genders.

Hasselstrom et al. [74]	n=203; 15-19 yrs; (88/115); Denmark	Longitudinal (8 year follow-up)	Linear regression	Combined relative strength score	Individual CVD risk factors and combined CVD risk score	Strength at baseline was inversely associated with %BF 8 years later in men but not women. Change in strength over 8 years was inversely associated with waist girth and %BF at follow-up in men but not women. Change in strength over 8 years was associated with change in %BF over 8 years in men but not women. No other risk factors were significantly related for either gender.
Haugen et al. [69]	n=1839; 15 yrs; (950/889); Norway	Cross-sectional	Bivariate correlation; Mediation analysis	Push ups; SLJ	Physical self-perceptions: Perceived athletic competence; Perceived physical appearance	Push ups and SLJ were positively associated with perceived athletic competence, perceived physical appearance and PA among both genders. Push ups and SLJ were found to mediate the relationship between PA and perceived athletic competence among both genders. The relationship between PA and perceived physical appearance was mediated by Push ups and SLJ for males only.
Heroux et al. [143]	n=736; 9-13 yrs; (374/362); Canada. n= 93; 10-13 yrs; (98/95); Mexico. n=179; 9-13 yrs; (86/93); Kenya.	Cross-sectional	Linear regression	GS	Triceps skinfold; WC; Weight status (BMI)	GS was not significantly associated with body composition variables in the Kenyan sample. GS was positively associated with BMI and WC but not skinfold among boys and girls in the Mexican and Canadian samples but only explained 9-14% of the variance (R^2 range = 0.09 - 0.14). The association was strongest for Mexican girls (R^2 = 0.32).
Hoekstra et al. [183]	n=2016; 12 and 15 yrs; (1018/998); Northern Ireland	Cross-sectional	Bivariate correlation; Linear	GS; VJ	Individual CVD risk factors	Associations were found between CVD risk factors and MF, adjusted for confounders. Adjustment for CRF attenuated most

			regression			associations. However, the association between skinfolds remained significant as did diastolic blood pressure for 15 yr old girls. No interaction between MF and CRF was found in the association with CVD risk factors.
Hruby et al. [77]	n=2793; grades 1-7; (1456/1337); USA	Longitudinal (4 year follow-up)	Logistic regression	Sit ups; Pull ups; BAH	Weight status (BMI)	Following adjustment for multiple confounders, achieving and maintaining 'adequate' fitness over the four years was associated with increased odds of being a healthy weight at follow-up.
Huang & Malina [144]	n=102,765; 9-18 yrs; (51825/50940); Taiwan	Cross-sectional	Non-linear quadratic model	1 minute Sit ups; SLJ	BMI	Poorer performance in Sit-ups and SLJ was evident in boys and girls in each age group with higher BMIs. The relationship becomes parabolic during adolescence and peaks of the parabola are sharper in boys than girls.
Huberty et al. [145]	n=826; 6-11 yrs; (391/435); USA	Cross-sectional	Non-linear mixed modelling (PROC NLMIXED procedure)	Fitnessgram: Push ups; Sit ups	Weight status (BMI)	Weight status was not a significant factor in describing differences in the mean number of Push ups or Sit ups. Weight status was a significant predictor in the model of meeting/exceeding the national standards for Push ups and borderline significant for Sit ups.
Huotari et al. [159]	1976: n=643; 15 yrs; (312/331); Finland 2001: n=579; 15 yrs; (308/271); Finland	Cross-sectional	General linear models	Sit ups; BAH; Pull ups; SLJ; MFI	BMI	In both sexes MFI was significantly lower among overweight/obese than normal weight participants in both study years.

Janz et al. [75]	n=112; 10.5 (at baseline); (54/58); USA	Longitudinal (5 year follow-up)	Partial correlation; Multiple linear regression	GS	Individual CVD risk factors	Change in GS and average GS over the five year period were significantly associated with WC and sum of skinfolds at follow-up, following adjustment for multiple confounders. GS explained 5% of the variance in year-5 WC
Johnson et al. [186]	n=625; 11-19 yrs; (290/335); Nigeria	Cross-sectional	t-test; Bivariate correlation	BME (Biering-Sørensen test)	Low back pain; BMI; Hip circumference; Waist-to-hip ratio; WC	There was a significant difference in BME between those with and without current back pain and those that had or hadn't had a past history of back pain. There were weak but significant inverse correlations between BME and BMI, Hip circumference, and waist to hip ratio. WC was borderline significant.
Johnson et al. [185]	n=625; 11-19 yrs; (290/335); Nigeria	Cross-sectional	Chi square test of association; Logistic regression	BME (Biering-Sørensen test)	Low back pain	The relative risks (OR and 95% CI) of developing back pain among those that had poor back muscles' endurance compared with those with moderate and good back endurance were (OR 0.52; CI 0.21–0.82) and (OR 0.97; CI 0.48–1.96) respectively. Chi square test of association result indicates that level of back muscle endurance was significantly associated with LBP in adolescents.
Joshi et al. [146]	n=6625; 5-17 yrs; (3084/3541); USA	Cross-sectional	Logistic regression; Chi-square test	Fitnessgram: Sit ups; Trunk lifts; Push ups	Weight status (BMI)	There was a significant difference in Sit ups and Push ups between normal weight and obese subjects in favour of normal weight. No significant differences were observed between weight groups for the trunk lift.
Kardinaal et	n=1116; 11-15 yrs;	Cross-sectional	Bivariate	GS	Radius BMC and	A number of bone parameters (notably

al. [172]	(0/1116); Europe		correlation; Multiple regression		BMD	BMC and BMD) were moderately to strongly associated with GS. In the multivariate model GS was an independent predictor of most bone parameters after additional adjustment for age and tanner stage.
Kim et al. [162]	n=6297; 5-14 yrs; NR; USA	Longitudinal (12 month follow-up)	Multiple logistic regression	Fitnessgram: Sit ups; Pull ups; BAH	Weight status (BMI)	Baseline upper body strength significantly predicted incidence of overweight 1 year later for boys and girls. However, adjustment for baseline BMI z-score attenuated the association.
Lloyd et al. [147]	n=200; 10-12 yrs; (91/109); USA	Cross-sectional	Bivariate correlation	Sit ups; Push ups; Pull ups	Sum of 2 skinfolds; BMI	Skinfolds and BMI were significantly correlated with Push ups and Sit ups. Approximately, 15% of the variance in Sit ups and 12% of the variance in Push-ups could be explained by skinfolds.
Lubans & Cliff [72]	n=106; 14.9(0.7); (54/52); Australia	Cross-sectional	Product of coefficients test	1RM bench press and leg press (absolute and relative)	Physical self-perceptions: Physical self-worth; Perceived physical strength	Physical self-worth was significantly associated with absolute strength for boys and with relative strength for girls. Perceived physical strength mediated the relationship between absolute strength and physical self-worth for boys. In girls the relationship between relative strength and perceived physical strength was not significant, nor was the mediated effect.
Mafanya & Rhoda [187]	n=181; 16(1.1) yrs; (97/84); South Africa	Cross-sectional	Logistic regression	Neck flexor endurance	Neck pain (Self-reported)	There was a significant association between neck pain and neck flexor muscle endurance.
Magnussen et al. [178]	n=1642; 9-15 yrs; (870/772);	Cross-sectional	Linear regression	Isokinetic strength score;	Individual CVD risk factors and combined	Individual CVD risk factors and the combined risk score were associated with

	Australia			Push ups; SLJ	CVD risk score	all MF phenotypes. Muscular endurance and power remained significant after adjustment for BMI. In multivariate analyses muscular power, CRF and the power x CRF interaction were all significant predictors of the combined CVD risk score.
Malina et al. [148]	n=6700; 7-17 yrs; (0/6700); Belgium	Cross-sectional	Partial correlation; t-test	Arm pull; BAH; Leg lifts; Sit ups; VJ; SLJ	Sum of 5 skinfolds	Significant partial correlations were found between skinfolds and the MF tests across age groups. Comparisons of MF between the leanest and fattest 5% showed that leaner girls performed significantly better than the fatter girls.
Malina et al. [149]	n=686; 6-13 yrs; (344/342); Mexico	Cross-sectional	MANCOVA	GS (absolute and Relative); Sit ups; SLJ	Weight status (BMI)	Grip strength was significantly lower for all normal weight subjects except for grade 1-3 boys. However, when compared against relative values normal weight was significantly better than overweight. No significant differences between weight groups were observed for SLJ or Sit ups performance.
Marsh [71]	n=192; 13-15 yrs; (113/79); Australia	Cross-sectional	Bivariate correlation; Partial correlation	Modified pull ups; Basketball throw; SLJ	Self-esteem/Physical self-perceptions: Appearance; Strength; Endurance; Flexibility; Health; Coordination; Activity; Body fat; Sports competence; Global physical self-concept; Global self-esteem.	MF was associated with a number of physical self-perceptions as well as physical self-concept and global self-esteem.

Martínez-Gómez et al. [59]	n=198; 13-17 yrs; (102/96); Spain	Cross-sectional	Multiple linear regression; ANCOVA	GS; SLJ; MFS	Adipocytokines	MFS was significantly and inversely associated with Adiponectin and Leptin. A significant difference was found between high and low MFS groups for both Adiponectin and Leptin.
Martinez-Gomez et al. [60]	n=1025; 14.8(1.2); (476/549); Europe	Cross-sectional	Partial correlation; Multiple regression	GS; SLJ; MFS	Inflammatory biomarkers; BMI	Weak but significant associations were found between MFS and BMI. WC was not related. MFS was significantly associated with inflammatory biomarkers, adjusted for confounders.
Mikkelsson et al. [65]	n=1121; 12-17 yrs at baseline; (801/880); Finland	Longitudinal (25 year follow-up)	Logistic regression	Sit ups	Tension neck; low back pain; knee injury (Self-reported)	Higher Sit ups at baseline was associated with reduced risk of tension neck in adulthood for women in the univariate model. This became borderline significant in the multivariate model. There was an increased risk of knee injury in men with high Sit ups at baseline in the multivariate model. No association was found for Sit ups and low back pain.
Minck et al. [150]	n= 181; 13.0; (83/98); Holland	Longitudinal (15 year follow-up)	Longitudinal linear regression with generalised estimating equations	Arm pull; BAH; VJ; Ten leg lifts	Sum of 4 skinfolds	In adjusted analyses skinfolds was longitudinally associated with VJ and leg lifts.
Moliner-Urdiales et al. [50]	n=363; 12.5-17.5 yrs; (177/186); Europe	Cross-sectional	Multiple regression	GS; VJ; SLJ	Adiposity: Sum of 6 skinfolds; WC; Bodpod; DXA	All measures of total and central adiposity were inversely associated with VJ and SLJ. A positive association was observed for GS and total adiposity measured by DXA only

						and between GS and WC.
Morano et al. [70]	n=260; 12.2(0.9); (140/120); Italy	Cross-sectional	Bivariate correlation; ANOVA	SLJ; Medicine ball throw	Body image; BMI; Physical self-perceptions: Coordination; Body fat; Sports competence; Physical ability	SLJ was inversely associated with BMI while ball throw was positively associated. SLJ was moderately and positively associated with perceived coordination, perceived sports competence, and perceived physical ability. SLJ was moderately and inversely associated with perceived body fat and body dissatisfaction for both genders. Ball throw was weakly and positively associated with perceived body fat in both genders.
Mota et al. [99]	n= 229; 12-15 yrs; (0/229); Portugal	Cross-sectional	ANCOVA; Partial correlation; Logistic regression	Fitnessgram: Sit ups, Push ups	Individual CVD risk factors and MRS	Analyses adjusted for confounders, found that girls in the highest MF group had lower BMI, better lipid profile, and had a lower MRS than those in the lowest MF group. MF was negatively associated with individual CVD risk factors and the MRS. Compared to those in the low MF group, those in the high and middle groups had significantly lower odds of a high MRS.
Newcomer et al. [108]	n=96; 10-19 yrs; (53/43); NR	Longitudinal (4 year follow-up)	Logistic regression	Back strength	Low back pain (Self-reported and diagnosed)	Subjects with higher back strength had a significantly higher percentage of positive responses to experiencing back pain ever and in the past year, after adjustment for confounders. There was also a significant positive association between 4-year increase in back flexor strength and past year back pain but not back pain ever. No significant association was found for 4-year change in back extensor strength and back pain. Diagnosed back pain was not associated with back strength.

O'Sullivan et al. [188]	n=1328; 14.1(0.2); NR; Australia	Cross-sectional	Multivariable multinomial logistic regression	BME (Biering-Sørensen test)	Back pain (Self-reported)	For females but not in males, better BME was associated with decreased odds for back pain made worse by sitting compared with both no back pain and back pain not made worse by sitting. The association for females between BME and back pain made worse by sitting remained similar after adjustment for covariates.
Ortega et al. [179]	n=2859; 13-18.5 yrs; (1357/1502); Spain	Cross-sectional	Non-parametric Mann-Whitney test	Eurofit: GS; BAH; SLJ	Low CRF related to future CVD risk	The group of adolescents with CRF indicative of future CVD risk performed significantly worse in GS (boys only), SLJ, and BAH.
Ortega et al. [30]	n=1142599; 10-19 yrs; (1142599/0); Sweden	Longitudinal (median 24 year follow-up)	Cox proportional hazards regression	GS; Knee extension strength; Elbow flexion strength	All-cause, CVD-, Cancer-, and Suicide-related mortality; Risk of psychiatric diagnosis	Higher strength was associated with approximately 20% reduced risk of all-cause mortality and 35% reduced risk of CVD-related mortality. Higher strength was associated with a 20-30% lower risk of death from suicide and 15-65% reduced risk of any psychiatric diagnosis. No association was found for cancer-related mortality. The effect size for low strength and all-cause mortality was similar to that for high BMI and blood pressure.
Padilla-Moledo et al. [34]	n=690; 6-17.9 yrs; (368/322); Spain	Cross-sectional	Multiple regression; Binary logistic regression	SLJ; Basketball throw; MFI	Psychological positive health; Health complaints; Health risk behaviours	With the exception of quality of peer relationships, the MFI was positively associated with all psychological positive health indicators. MFI was also inversely associated with tobacco and alcohol use. Additional adjustment for BMI didn't change the findings.
Pate et al.	Sample 1: n=2520;	Cross-sectional	Bivariate	1 minute Sit ups	Sum of 2 skinfolds	Sit ups were weakly and inversely

[151]	6-16 yrs; NR; USA Sample 2: n=2262; 6-18 yrs; NR; USA		correlation; Stepwise multiple regression; Kruskal-Wallis test			associated with skinfolds for both genders Among sample 1, significant differences in Sit-ups were found between weight groups for both genders in favour of leaner subjects. In sample 2, nearly identical findings were observed.
Perry et al. [109]	n=1608; 14.1(0.2) yrs; (825/783); Australia	Cross-sectional	Logistic regression	Back extension; Sit ups; SLJ; Basketball throw	Back pain (Self-reported and diagnosed)	Increased odds of experiencing back pain in the past month was associated with greater abdominal endurance in girls. Increased odds of diagnosed back pain was associated with both reduced back endurance and greater back endurance Lower odds of back pain ever was associated with greater SLJ.
Pino-Ortega et al. [152]	n=293; 10(0.8) yrs; (137/156); Spain	Cross-sectional	Multinomial logistic regression	GS; SLJ	Weight status (BMI)	The odds of being in the high GS group was significantly lower among normal weight subjects compared with overweight. Conversely, normal weight subjects had significantly higher odds of being in the high SLJ group compared with overweight subjects.
Pissanos et al. [153]	n=80; 6-10 yrs; (40/40); USA	Cross-sectional	Stepwise multiple linear regression	1 minute Sit ups; SLJ	Sum of 2 skinfolds	Skinfolds were significantly inversely associated with SLJ but not Sit ups.
Pongprapai et al. [154]	n=259; 6-12 yrs; (125/134); Thailand	Cross-sectional	ANOVA	Sit ups	Weight status	There were significant differences in Sit ups between weight groups for both genders in favour of leaner subjects.
Ransdell et al. [49]	n=20; 14-17 yrs; (0/20); NR	Experimental (2-arm uncontrolled trial)	Bivariate correlation	Modified Push ups; Sit ups	Physical self-perceptions: Sports competence; Physical condition; Body	Changes in MF over the intervention period were not significantly associated with changes in any physical self-perceptions.

					attractiveness; Strength and muscularity; Physical self-worth	
Raudsepp & Jurimae [163]	n=77; 10.5(0.6) yrs; (0/77); NR	Cross-sectional	Bivariate correlation	Eurofit: GS; Sit ups; BAH; SLJ	Sum of 5 skinfolds	GS and Sit ups were not related to skinfolds. SLJ and BAH were inversely associated with skinfolds.
Raudsepp & Jurimae [160]	n=203; 7-10 yrs; (203/0); NR	Cross-sectional	Bivariate correlation; Partial correlation	Eurofit: GS; Sit ups; BAH; SLJ	Sum of 5 skinfolds	SLJ and BAH were significantly associated with skinfolds among all age groups. Associations remained after additional adjustment for age and MVPA. Sit ups was associated with skinfolds among 8 and 10 yr olds but GS was not related to skinfolds among any age group.
Rice et al. [175]	n=35; 14-18 yrs; (0/35); NR	Cross-sectional	Bivariate correlation; Stepwise multiple regression	1RM leg press and bench press; Isokinetic strength	Whole body and spine BMC and BMD	Leg strength was significantly associated with all bone variables while Isokinetic strength was significantly positively correlated with BMC. The regression analysis indicated that Leg strength was not an independent predictor of any bone mass variables.
Ruiz et al. [61]	n=416; 13-18.5 yrs; (230/186); Spain	Cross-sectional	Multiple regression; ANCOVA	GS; SLJ; MFS	Inflammatory biomarkers; Skinfolds; %BF	After adjustment for multiple confounders including CRF, MFS was significantly inversely associated with specific inflammatory biomarkers among overweight adolescents. Overweight adolescents with high MFS had significantly lower skinfolds and %BF than those with low MFS.
Ruiz et al.	n=1820; 13-18.5	Cross-sectional	ANCOVA,	GS; SLJ	Cognitive	GS and SLJ were not associated with

[121]	yrs; (862/958); Spain		Binary logistic regression		performance (Test of educational ability: verbal, numeric and reasoning skills)	cognitive performance.
Sacchetti et al. [155]	n=497; 8-9 yrs; (256/241); Italy	Cross-sectional	Kruskal-Wallis test; t-test	Medicine ball throw; SLJ	Weight status (BMI)	For both genders SLJ became worse across increasing weight categories. The opposite occurred for the Medicine ball throw.
Sallis et al. [193]	n=528; 10.5(0.5) yrs; (274/254); USA	Cross-sectional	Multiple linear regression; Partial correlation	Fitnessgram: Pull ups; Sit ups	Sum of 2 skinfolds	Pull ups and Sit ups were inversely associated with skinfolds.
Salminen et al. [189]	n=76; 15 yrs; (34/42); Finland	Cross-sectional	t-test	6-stage Sit ups; Isometric abdominal hold; BME	Low back pain	Endurance of the abdominal and back muscles was significantly lower in the group with back pain. No differences were found for 6-stage Sit ups.
Salminen et al. [191]	n= 62; 15 yrs; (29/33); Finland	Longitudinal (3 year follow-up)	ANOVA	6-stage Sit ups; Isometric abdominal hold; BME	Low back pain	Diminished abdominal and back muscle endurance at baseline was associated with increased frequency of back pain. Low muscle endurance at baseline did not predict future back pain.
Sjölie et al. [66]	n=86; 14.7(0.6) yrs at baseline; (50/38); Norway	Longitudinal (3 year follow-up)	Binary logistic regression; ANOVA	BME (modified Biering-Sørensen test)	Low back pain (Self-reported)	There was a significant difference in BME at baseline between those with and without back pain. Those with higher BME had significantly decreased odds of back pain at baseline after adjustment for confounders. There was a significant difference in baseline BME between those with and without back pain at follow-up for girls but not boys. Baseline BME significantly predicted back pain at follow up after

						adjustment for confounders.
Slaughter et al. [156]	n=68; 7-12 yrs; (68/0); USA	Cross-sectional	Bivariate Correlation	SLJ; VJ	Sum of 2 skinfolds; %BF	SLJ and VJ were moderately inversely associated with both %BF and skinfolds.
Slaughter et al. [164]	n=50; 7-12 yrs; (0/50); USA	Cross-sectional	Bivariate Correlation	SLJ; VJ	%BF	SLJ and VJ were not significantly associated with %BF.
Smith et al. [73]	n=1435; 14(0.2) yrs; (733/702); Australia	Cross-sectional	Linear regression	BME (Biering-Sørensen test)	Global self-esteem; Self-efficacy; Depressed mood; Behavioural and emotional problems; BMI; Low back pain	Back pain in the last month was not associated with BME. Higher BMI was inversely associated with BME. Self-efficacy and self-esteem were positively associated with BME. Behavioural problems score was inversely related to BME. In the multivariate model BMI was the most significant factor related to BME.
Steene-Johannessen et al. [57]	n=1592; 9 and 15 yrs; (854/738); Norway	Cross-sectional	ANOVA; Partial correlation; Multiple regression; Logistic regression	GS; Sit ups; BME; SLJ; MFS	Individual CVD risk factors and combined CVD risk score	There were significant partial correlations between MFS and both individual and combined CVD risk factors. CVD risk declined with increasing MFS among all age and sex subgroups. MFS was a significant predictor of combined CVD risk score, following adjustment for confounders including CRF. The association was found for overweight and non-overweight youth. Overweight youth in the lowest tertile of MFS showed the poorest cardiovascular profile.
Steene-Johannessen et al. [62]	n=836; 9 yrs; NR; Norway	Cross-sectional	Partial correlation; ANOVA; Multiple regression	GS; Sit ups; BME; SLJ; MFS	Inflammatory biomarkers	There were significant inverse partial correlations between MFS and inflammatory markers for both genders. There was a strong graded relationship across quintiles of MFS, with inflammation

						levels decreasing from low to high MFS. MFS was a significant predictor of C-reactive protein and Leptin levels independent of CRF and WC.
Thorsen et al. [180]	n=47; 16.9(0.3) yrs; (47/0); Sweden	Cross-sectional	Bivariate correlation	Isokinetic strength	Lipoprotein	Lipoprotein was positively correlated with isokinetic leg strength.
Tokmakidis et al. [157]	n=709; 8.9(1.6); (381/328); Greece	Cross-sectional	MANOVA; MANCOVA	Sit ups; SLJ	Weight status (BMI)	Normal weight and overweight males performed better than obese males in SLJ and Sit ups. For females, normal weight performed better than overweight and obese in the SLJ and Sit ups. Associations were unchanged or became stronger when corrected for age.
van Langendonck et al. [173]	n=21; 8.7(0.7) yrs; (0/21); Belgium	Cross-sectional	Bivariate correlation; Partial correlation	Isokinetic strength; Combined strength score	Multiple site BMD, BMC, and bone area	Significant associations were found between the strength score and BMC at all sites, BMD at most sites, and bone area at all sites. Controlling for height revealed somewhat lower but still significant associations. Controlling for lean mass caused all of the associations to become non-significant.
Vicente-Rodríguez, G. et al. [33]	n=278; 13-18.5 yrs; (109/169); Spain	Cross-sectional	Hierarchical multiple regression	Eurofit: GS; BAH; SLJ	Whole body BMC and BMD	For males GS, BAH, and SLJ were all independent predictors of whole body BMC. For females GS and SLJ were also independent predictors but BAH was not. No independent relationships were observed in males or females between MF variables and bone mass after the models were adjusted for lean mass.
Wang et al.	n=258; 10-13 yrs;	Longitudinal (2	Hierarchical	Upper and	Multiple site BMC	BMC of arm and leg correlated

[53]	at baseline; (0/258); Finland	year follow-up)	lineal models with random effects.	lower body maximal strength		significantly with strength of 1 elbow flexors and knee extensors, respectively. Similarly, the change in BMC and change in strength were also correlated significantly in the upper and lower limbs.
Weeks et al. [55]	n=81; 13.8(0.4) yrs; (37/44); Australia	Experimental (8 month RCT)	Forward stepwise multiple regression	VJ	Multiple site BMC, BMD and bone area	Change in VJ was not a significant predictor of change in any of the measured bone parameters.
Witzke & Snow [176]	n=54; 14.6(0.5) yrs; (0/46); USA	Cross-sectional	Bivariate correlation; Stepwise regression	Leg strength	Multiple site BMC and BMD	Leg strength was significantly correlated with multiple site BMD but was not an independent predictor of BMD at any site in the regression analysis. Leg strength was significantly correlated with BMC at some sites.
Woods et al. [130]	N= 94; 9-11 yrs; (38/56); USA	Cross-sectional	Bivariate correlation; Multiple regression	Combined strength score; Combined endurance score; Pull ups; Push ups; BAH; VMPU; NYMPU	%BF	Combined strength and muscular endurance scores were not correlated with %BF. However, all individual MF tests were associated with %BF. Pull ups, VMPU, BAH and Push ups were all significant predictors of %BF in multivariate analyses. NYMPU was not a significant predictor of %BF.

Electronic Supplementary Material, Table S2. Risk of bias checklist with scores assigned

Citation	Random selection of study participants or sites	Description of study sample	Assessment of muscular fitness	Assessment of health-related outcome	Confounder adjustment	Total /5
Afghani et al. [167]	1	1	0	1	0	3
Almuzaini [145]	0	1	1	1	0	3
Andersen [165]	1	1	1	0	1	4
Andersen [184]	1	1	1	0	1	4
Annesi [132]	0	1	1	1	0	3
Ara et al. [133]	1	1	1	1	1	5
Ara et al. [158]	1	0	1	1	1	4
Artero et al. [83]	1	1	1	1	1	5
Artero et al. [56]	1	1	1	1	1	5
Artero et al. [58]	1	1	1	1	1	5
Barnekow-Bergkvist et al. [64]	1	1	1	1	1	5

Barnekow-Bergkvist et al. [181]	1	1	0	1	1	4
Barnekow-Bergkvist et al. [54]	1	1	1	1	1	5
Benson et al. [32]	0	1	1	1	0	3
Benson et al. [166]	1	1	1	1	1	5
Bovet et al. [134]	1	1	0	1	1	4
Brandon & Fillingim [182]	0	1	0	1	1	3
Brunet et al. [135]	0	1	1	1	1	4
Butterfield et al. [136]	0	0	1	1	1	3
Cardon et al. [110]	1	1	1	1	1	5
Castelli et al. [120]	0	1	1	1	1	4
Castelli & Valley [80]	0	1	1	0	1	3

Castro-Piñero et al. [137]	1	1	1	1	0	4
Chen et al. [138]	1	1	1	1	1	5
Chen et al. [139]	1	1	1	1	1	5
Cheng et al. [168]	0	1	1	1	1	4
Cheng et al. [52]	0	1	1	1	1	4
Clark et al. [51]	0	1	1	1	1	4
Coe et al. [35]	0	1	1	1	0	3
Cureton et al. [140]	0	1	1	1	1	4
Deforche et al. [82]	1	1	1	1	1	5
Du Toit et al. [118]	0	1	1	1	1	4
Duppe et al. [174]	1	1	0	0	1	3
Dwyer et al. [117]	1	1	0	0	1	3
Edwards et al. [119]	1	1	1	1	1	5

Feldman et al. [190]	0	1	0	1	1	3
Fogelholm et al. [81]	1	1	0	0	1	3
Fonseca et al. [169]	0	1	1	1	0	3
Foo et al. [94]	1	1	1	1	1	5
Freitas et al. [76]	1	1	1	1	1	5
García-Artero et al. [177]	1	1	1	1	1	5
Ginty et al. [170]	0	1	0	1	1	3
Gonzalez-Suarez & Grimmer-Somers [142]	1	1	1	1	1	5
Gonzalez-Suarez et al. [141]	0	1	1	1	1	4
Gracia-Marco et al. [171]	1	1	1	1	1	5
Grøntved et al. [39]	1	0	1	1	1	4
Grund et al. [161]	0	1	1	1	1	4
Hands et al. [192]	1	1	1	1	1	5

Hasselstrom et al. [74]	1	1	1	1	1	5
Haugen et al. [69]	0	1	1	1	1	4
Heroux et al. [143]	0	1	0	1	1	3
Hoekstra et al. [183]	1	1	1	1	1	5
Hruby et al. [77]	1	1	1	1	1	5
Huang & Malina [144]	1	1	1	1	1	5
Huberty et al. [145]	0	1	1	1	1	4
Huotari et al. [159]	1	1	1	0	1	4
Janz et al. [75]	0	1	1	1	1	4
Johnson et al. [186]	1	1	1	0	0	3
Johnson et al. [185]	1	1	1	0	0	3
Joshi et al. [146]	0	1	1	1	1	4
Kardinaal et al. [172]	1	1	0	1	1	4

Kim et al. [162]	0	1	1	1	1	4
Lloyd et al. [147]	0	1	1	1	1	4
Lubans & Cliff [72]	0	1	1	1	0	3
Mafanya & Rhoda [187]	0	1	1	1	0	3
Magnussen et al. [178]	1	1	1	1	1	5
Malina et al. [148]	1	1	0	1	1	4
Malina et al. [149]	0	1	1	1	1	4
Marsh [71]	0	1	0	1	1	3
Martínez-Gómez et al. [59]	0	1	1	1	1	4
Martinez-Gomez et al. [60]	1	1	1	1	1	5
Mikkelsson et al. [65]	1	1	1	0	1	4
Minck et al. [150]	0	1	0	1	1	3
Moliner-Urdiales et al. [50]	1	1	1	1	1	5

Morano et al. [70]	0	1	1	1	1	4
Mota et al. [99]	0	1	1	1	1	4
Newcomer et al. [108]	0	1	1	1	1	4
O'Sullivan et al. [188]	0	0	1	1	1	3
Ortega et al. [179]	1	1	1	0	1	4
Ortega et al. [30]	1	1	1	1	1	5
Padilla-Moledo et al. [34]	1	1	1	1	1	5
Pate et al. [151]	0	1	0	1	1	3
Perry et al. [109]	0	1	1	1	1	4
Pino-Ortega et al. [152]	1	1	1	1	0	4
Pissanos et al. [153]	0	1	1	1	1	4
Pongprapai et al. [154]	1	1	0	0	0	2
Ransdell et al. [49]	1	1	1	1	1	5

Raudsepp & Jurimae [163]	0	1	1	0	1	3
Raudsepp & Jurimae [160]	0	1	1	1	1	4
Rice et al. [175]	0	1	1	1	0	3
Ruiz et al. [61]	1	1	1	1	1	5
Ruiz et al. [121]	1	1	1	1	1	5
Sacchetti et al. [155]	1	1	1	1	1	5
Sallis et al. [193]	0	1	1	0	1	3
Salminen et al. [189]	1	1	1	1	1	5
Salminen et al. [194]	1	1	1	1	1	5
Sjölie et al. [66]	0	1	1	1	0	3
Slaughter et al. [156]	0	1	1	1	0	3
Slaughter et al. [164]	0	1	1	1	0	3
Smith et al. [73]	0	1	1	1	1	4

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Steene-Johannessen et al. [57]	1	1	1	1	1	5
Steene-Johannessen et al. [62]	1	1	1	1	1	5
Thorsen et al. [180]	0	1	0	1	1	3
Tokmakidis et al. [157]	0	1	1	1	1	4
van Langendonck et al. [173]	0	1	0	1	1	3
Vicente-Rodríguez, G. et al. [33]	1	1	1	1	1	5
Wang et al. [53]	0	1	1	1	0	3
Weeks et al. [55]	0	1	0	1	1	3
Witzke & Snow [176]	0	1	1	1	1	4
Woods et al. [130]	0	1	1	1	1	4