Smith, Jordan J.; Eather, Narelle; Weaver, R. Glenn; Riley, Nicholas; Beets, Michael W.; Lubans, David R.; "Behavioral correlates of muscular fitness in children and adolescents: a systematic review." Published in *Sports Medicine Vol. 49, Issue 6, p. 887-904* (2019).

Available from: http://dx.doi.org/10.1007/s40279-019-01089-7

Behavioral correlates of muscular fitness in children and adolescents: A systematic review

Running head: Review of muscular fitness and health behaviors in youth

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Acknowledgements: Jordan Smith would like to thank Jennie Thomas and the Hunter Medical Research Institute for providing travel funding.

Funding: No sources of funding were used to assist in the preparation of this article

Conflict of interest: Jordan Smith, Narelle Eather, R. Glenn Weaver, Nicholas Riley, Michael Beets and David Lubans declare they have no conflicts of interest with the content of this article.

ABSTRACT

Background: Muscular fitness (MF) is considered a powerful marker of health, but the extent to which common health behaviors are associated with MF during childhood and adolescence is currently unclear.

Objective: We aimed to conduct a systematic review of studies investigating associations between MF (i.e., strength/power, local muscular endurance) and physical activity, sedentary behaviors and sleep in children and adolescents.

Methods: A systematic search of six electronic databases was performed on 8th March, 2017. Search results were screened for relevance and studies conducted with children and adolescents (3-18 years) that explored associations between MF and physical activity, sedentary behavior, or sleep were considered eligible. Data were extracted and checked by a second author. The proportion of studies reporting a statistically significant association between each MF component and behavioral variables was calculated, and additional coding was conducted to account for risk of bias.

Results: There was consistent evidence for a positive association between MF and physical activity. For both MF components, there was support for objectively measured physical activity, particularly for activity of vigorous intensity. Sports participation was also consistently linked with both MF components, whereas the association with active transport was inconsistent. For both MF components, associations with sedentary behaviors were inconsistent irrespective of measurement method, and the association between MF and sleep was considered uncertain.

Conclusions: The available evidence supports a link between MF and physical activity, particularly for vigorous intensity activity and organised sports participation. Conversely, there is limited support for an association with sedentary behaviors, and more research exploring MF and sleep is required.

Key points:

- There is support for a positive association between muscular fitness and physical activity
- Sedentary behaviors do not appear to be linked with muscular fitness.
- There is a lack of research exploring muscular fitness and sleep in young people

1 BACKGROUND

Physical fitness during childhood and adolescence has been identified as a powerful marker of health [1]. Traditionally, studies examining the links between physical fitness and health have focused on poor cardio-respiratory fitness (CRF) and unhealthy body composition, both of which are now widely accepted risk factors for chronic disease [2, 3]. In more recent years, a growing body of evidence has demonstrated the unique and complementary benefits of muscular fitness (MF) for a variety of health-related outcomes [1]. A previous systematic review and meta-analysis of studies with school-aged youth found strong evidence for associations between MF and cardiovascular risk, total and central adiposity, skeletal health, and self-esteem [4]. Importantly, many of these benefits were independent of CRF, emphasizing the unique role of MF in promoting positive health and wellbeing. As for other health-related fitness components, MF has a strong genetic basis with prior research reporting a wide range of heritability estimates (e.g., 30-80%) for short and long duration anaerobic tasks that appear to depend on the nature of the muscle contraction and test being used [5]. Despite this, it remains important to understand how modifiable health behaviors might influence MF, particularly during the critical developmental years of childhood and adolescence.

The term ‘muscular fitness’ encompasses three related but distinct aspects of musculoskeletal functioning, namely maximal strength, muscular power, and local muscular endurance. Maximal strength refers to the absolute amount of force that a muscle can exert, muscular power (also referred to as ‘explosive strength’) relates to the rate of force production (i.e., force per unit time), and local muscular endurance refers to the ability of muscles to exert force repeatedly under sub-maximal load [6]. While maximal strength and muscular power reflect unique aspects of physical function, they are very closely related. For example, field-based measures of power are moderately to strongly correlated with criterion measures of maximal strength [7]. On the other hand, local muscular endurance is a distinctly different aspect of musculoskeletal functioning, often showing differing associations with behavioral [8] and health [9] outcomes. Prior research exploring the links between MF and health has been limited by a failure to distinguish between these separate dimensions of MF [7].

Of concern, secular declines in young peoples' MF have been reported across the globe [10-20], which have coincided with increases in sedentary behaviors (i.e., activities performed whilst sitting or lying down that involve minimal energy expenditure) [21] and declines in both physical activity (i.e., bodily movement resulting in increased energy expenditure) [22, 23] and total sleep duration [24]. With global trends worsening, there is a clear need to identify effective strategies to support the development and maintenance of MF throughout childhood and adolescence. The promotion of muscle-strengthening activities such as resistance training (RT) is an obvious approach for developing MF. However, it is likely only a small proportion of youth will participate in structured RT, as is evident in global participation estimates for sports and recreational activities [25]. Rather, the average child or adolescent will habitually engage in a variety of physical activities, such as general play, active transport, and organized sports. Each of these physical activity contexts, either alone or in combination, might contribute to the development and maintenance of MF [26, 27]. Moreover, the intensity of physical activity performed might be an important indicator of the benefits for MF, irrespective of physical activity type [28]. With this in mind, there is a need to better understand how the qualitative (e.g., type) and quantitative (e.g., intensity) aspects of physical activity are linked with MF in this population.

Of note, sedentary behaviors and sleep may also influence young peoples' MF, either via their direct physiological effects or via displacement of other fitness-promoting activities. Previous studies have reported associations between MF and sedentary behaviors [29, 30]; however, a recent systematic review of sedentary behaviour and health indicators identified few studies examining this association and the quality of evidence was found to be low-to-moderate [31]. Similarly, only a small number of studies have explored the link between sleep characteristics and MF, but significant associations have been reported among young adults [32, 33]. The literature is less clear for young people, but studies have reported associations between child and adolescent sleep characteristics (i.e., sleep duration/quality) and other health-related fitness components [34, 35]. It therefore seems plausible that an association might also exist for MF. If this is the case, it would further strengthen the case for contemporary pediatric health promotion guidelines that address behaviors across the entire movement continuum (i.e., from vigorous intensity physical activity through to sleep) [36].

While seemingly intuitive, the nature of the associations between MF and physical activity, sedentary behaviors and sleep in young people are not well understood. A greater understanding of these relationships may assist researchers and practitioners to better design and adapt health promotion interventions that aim to support the development and maintenance of MF during childhood and adolescence. However, a comprehensive synthesis of these associations has yet to be conducted. Therefore, the purpose of the present paper is to conduct a systematic review of the scientific literature examining associations between MF (i.e., maximal strength/power and local muscular endurance) and physical activity, sedentary behaviors and sleep among children and adolescents (3-18 years).

2 METHODS

2.1 Identification of studies

The conduct and reporting of this systematic review complies with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [37]. A systematic search of six electronic databases (i.e., PubMed, Scopus, SPORTDiscuss, EMBASE, PsycINFO, and OVID Medline) was performed on 8th March, 2017 and search results indexed within each database from date of inception up to the search date were screened by two authors (JS and NR) using Covidence systematic review software (Veritas Health Innovation, Melbourne, VIC). The following search strings were used to identify relevant articles: "*musc* fitness*" OR "*musc* strength*" OR "*musc* endurance*" OR "*musc* power*" OR *fitness* OR *strength* OR *power* OR "*motor fitness*" OR "*motor skill*" AND *adolescen** OR *teen** OR *child** OR *student** OR *youth* OR "*high school*" OR "*secondary school*" OR "*middle school*" OR "*elementary school*" OR "*primary school*" OR "*school-aged*" AND "*physical activity*" OR *activity* OR *active* OR "*active travel*" OR "*active transport**" OR *exercise* OR *sport** OR *movement* OR *sleep** OR *sedentar** OR *screen** OR *inactivity* OR *behavio**. Where possible search results were limited by language (English), species (human), source type (journals), and age (birth-18 years). In the first stage, search results were screened for relevance by title and abstract. Due to the large number of search results it was considered onerous to conduct title and abstract screening in duplicate. Therefore, search results were halved and screened separately by JS and NR. To prevent the loss of potentially relevant articles, a conservative screening approach was adopted and only search results that were obviously irrelevant were excluded at this stage Studies passing through to the second stage were then evaluated by full text review. In addition to the results from the database search, relevant articles from the authors' own bibliographic libraries, and those found by checking the reference lists of included articles were retrieved.

2.2 Criteria for inclusion/ exclusion

Two authors (NE and JS) independently assessed the eligibility of studies during full-text review, which were compared and agreed upon prior to inclusion. Studies were considered eligible if they satisfied the following criteria: (i) study participants were typically developing children/adolescents aged 3 to 18 years (i.e., special populations including elite athletes and youth with physical or psychological disorders were excluded); (ii) study provides a quantitative assessment of MF (i.e., maximal strength/power or local muscular endurance); (iii) study provides a quantitative assessment of physical activity, sedentary behavior, or sleep; (iv) study quantitatively examined the association between MF and physical activity, sedentary behavior, or sleep; and (v) study published in English in a peer-reviewed journal. Cross-sectional, longitudinal and experimental studies were all eligible for inclusion, assuming they satisfied the criteria above. After discussing discrepancies, consensus was reached on all studies included in the final manuscript.

2.3 Criteria for risk of bias assessment

Risk of bias was assessed independently by two authors (JS and RGW) using a list of 6 items developed from the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [(38)] and Consolidated Standards of Reporting Trials (CONSORT) [(39)] checklists: (1) study design allows for causal inference, (2) random selection of study participants and/or study sites, (3) detailed description of sample characteristics, (4) valid assessment of MF, (5) valid assessment of physical activity/sedentary behavior/sleep, and (6) adjustment for relevant confounders in analysis (i.e., age, sex, socio-economic status, and CRF). Further detail regarding the criteria for risk of bias coding can be seen in Electronic Supplementary Material Table S1. Consistent with previously established methods [40], each item was rated as either "high risk of bias", "moderate risk of bias", or "low risk of bias" based on pre-specified criteria. Of the six items assessed, items 1, 4, 5, and 6 were considered to contribute most to risk of bias, and a global rating based on these four criteria was generated as follows: "low" when no items were rated as having a high risk of bias, "moderate" when one component was rated as having a high risk of bias, and "high" when two or more components were rated as having a high risk of bias [40]. Following independent assessment, risk of bias ratings from the two authors were compared and discrepancies were decided upon by another author (NE) using majority consensus. Kappa analysis was used to evaluate inter-rater agreement, and Cohen's values [41] were used for interpretation: 0.01 to 0.20 (slight agreement), 0.21 to 0.40 (fair agreement), 0.41 to 0.60 (moderate agreement), 0.61 to 0.80 (substantial agreement), and 0.81 to 1.0 (almost perfect agreement).

2.4 Data extraction

Data were extracted by RGW using a purpose-designed extraction template in Microsoft Excel and checked for accuracy by a second author (JS). Information regarding sample characteristics, research design, measurement of fitness and behavioral outcomes, analytical methods and study findings was extracted. Where findings from multiple analyses were presented, we extracted the results of the most comprehensive analysis (i.e., multivariate/adjusted). Studies often utilised several measures of MF, making it challenging to synthesise research findings. In these instances, data from the most valid test for each component of MF were prioritised, based on recent evidence for test validity and reliability [7, 42, 43]. Specifically, data from lab-based criterion measures (e.g., 1 repetition maximum [1RM] testing, maximum repetitions at 50% of 1RM) were prioritised when reported. If only field-based measures were used, we considered the standing long jump test and handgrip dynamometry to be the most valid measures of maximal strength/power [7]. There is no expert consensus on the most valid field-based measures of local muscular endurance, and prior research suggests some of these tests have questionable criterion validity [44]. Therefore, if studies reported results for multiple measures of muscular endurance, we considered the association to be 'significant' if the majority of reported associations were statistically significant and if this rating was consistent with the study authors' overall conclusions. The same logic was applied in cases where mixed findings were reported for separate sub-groups. Finally, if the study used a composite MF index calculated using the sum or mean of standardized values for strength/power and muscular endurance, the study was included in the evaluation of both MF components.

2.5 Quantitative synthesis

Following the extraction of data, included studies were grouped according to health behavior: (i) physical activity, (ii) sedentary behavior, or (iii) sleep. There was substantial heterogeneity in the assessment of MF and health behaviours, and analytical methods employed (e.g., ANOVA, ANCOVA, simple/multivariate linear regression, t-test, bivariate/partial correlation analysis etc), which precluded meta-analysis. Instead, a descriptive synthesis outlining the 'consistency' of associations was considered most appropriate. Within each category, associations with measures of 'maximal strength/power' and 'local muscular endurance' were coded separately as 'associated with MF' or 'not associated with MF', and the overall proportion of studies reporting statistically significant associations with the MF component was calculated.

Findings were summarised using the method first employed by Sallis et al. [45]. Specifically, 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 that outcome, the result was classified as 'inconsistent' and 'uncertain', respectively (?); and if ≥60% of studies reported a significant association, the result was classified as 'positive' (+) or 'negative' (-) based on the direction of association. Additional coding was performed to account for risk of bias using an adaptation of the method proposed by Lubans et al. [46]. Specifically, studies with a high risk of bias were excluded and if ≥60% of remaining studies (when ≥4 available) reported a significant association the result was upgraded to 'consistent positive' (++) or 'consistent negative' (– –). Similarly, if the proportion of studies showing a significant association declined following the exclusion of high risk of bias studies, the summary association was downgraded. Finally, considering associations between MF and behaviors might vary depending on the type of test used, findings for the most commonly used tests were extracted and analysed separately using the method described above (without additional coding for risk of bias).

3 RESULTS

3.1 Overview of studies

The systematic search located 16,347 potentially relevant titles, following initial exclusion of duplicates (Figure 1). After excluding based on irrelevant title and abstract, full-text was located for 353 articles and 76 articles were retained following full-text review. A further 11 articles not identified through the original search were located in the authors' own libraries and the reference lists of included articles. Consequently, a total of 87 studies were included in the review, which examined associations between MF and physical activity (*n* = 76), sedentary behaviors (*n* = 25), and sleep (*n* = 2). The number of participants within included studies ranged from 44 to 649,442, and studies were cross-sectional (*n* = 72), longitudinal (*n* = 13) and experimental (*n* = 2) in design. The experimental studies included one randomized controlled trial [(47)] and one non-randomized controlled trial [(48)].

A variety of MF measures were used across studies, with the most commonly used measures being handgrip dynamometry (31/87 [35.6%] studies), sit-ups/curl-ups (31/87 [35.6%] studies), standing long/broad jump (27/87 [31.0%] studies), push-ups (13/87 [14.9%] studies), and composite indices of MF incorporating ≥ 2 different MF measures (14/87 [16.1%]). Other less frequently used tests included the vertical jump/squat jump, seated chest pass/medicine ball throw, flexed/bent arm hang, pull-ups, plank hold, leg press, bench press/chest press, arm curls, back extension, leg extension, and isokinetic or strain gauge dynamometry (using various muscle groups). Additional detail regarding study characteristics and a summary of findings by behaviour are provided in Electronic Supplementary Material Tables S2 to S4. A summary of the associations between health behaviors and 'maximal strength/power' and 'local muscular endurance' can be found in Tables 1 and 2, respectively. In addition, a summary of associations between behaviors and the five most commonly used MF measures is provided in Table 3.

3.2 Overview of study quality

The risk of bias for included studies is presented in Table 4. Based on the global rating, 58/87 (66.7%) studies were rated as having a high risk of bias, 25/87 (28.7%) were rated having a moderate risk of bias, and 4/87 (4.6%) were rated as having a low risk of bias. The most poorly satisfied criterion was criterion 1 (i.e., study design allows for causal inference), with 72/87 (82.6%) studies receiving a high risk of bias rating. The most well satisfied criterion was criterion 2 (i.e., random selection of study sites and/or participants) with 21/87 (24.1%) studies receiving a low risk of bias rating. Inter-rater agreement was found to be 'substantial' ($\kappa = 0.77$).

3.3 Muscular fitness and physical activity

In total, 77/87 (88.5%) studies examined the relationship between MF and physical activity, of which 63/77 (81.8%) were cross-sectional, 12/77 (15.6%) were longitudinal, and 2/77 (2.6%) were experimental. Of these, 65/77 (84.4%) studies assessed maximal strength/power and 53/77 (68.8%) studies assessed local muscular endurance. One of the experimental studies assessed strength/power only, whereas the other assessed both strength/power and muscular endurance. Eiholzer et al. [(47)] reported that changes in strength/power and muscular endurance did not correlate with changes in spontaneous physical activity energy expenditure. Conversely, Stenevi-Lundgren et al. [(48)] found total physical activity was weakly but significantly associated with some (but not all) measures of strength/power. Of the longitudinal studies, 12/12 (100%) assessed strength/power, and 9/12 (75%) assessed muscular endurance, but there was substantial heterogeneity in populations (i.e., age, sample size), follow-up periods (i.e., from one to 25 years), MF measures, physical activity measures, and analytical methods. For example, studies explored baseline MF measures as predictors of later physical activity [(49-54)], baseline physical activity as a predictor of later MF [(48, 55, 56)], as well as associations between changes in MF and changes in physical activity [(47, 57-59)]. Associations differed markedly between and within studies, with some showing mixed associations for different MF measures (at times in opposing directions) [(49, 52, 55)], and for different population sub-groups [(50, 57, 59)]. Consequently, the longitudinal relationship between MF and physical activity was considered unclear.

3.3.1 Maximal strength/power

Measures of strength/power were positively associated with physical activity in 43/65 (66.2%) studies, and in 16/26 (61.5%) after excluding high risk of bias studies (Table 1). Consequently, the summary association was classified as 'consistent positive' (++). Overall, when significant associations were reported the strength of association tended to be weak-to-moderate. Included studies used a variety of objective and self-report measures to assess physical activity. Accounting for risk of bias improved the rating for objectively measured physical activity (8/11 [72.7%] studies; rating = ++), but the association with self-reported physical activity was downgraded (9/16 [56.3%] studies; rating = ?). Overall, 11/65 (16.9%) studies reported associations between strength/power and accelerometer-determined physical activity intensity. After accounting for risk of bias, light (LPA) and moderate intensity activity (MPA) were not associated with strength/power (1/5 [20.0%] and 1/8 [12.5%] studies, respectively; rating = 0), whereas there was a 'consistent positive' association for vigorous (VPA) and moderate-to-vigorous (MVPA) intensity activity (7/9 [77.8%] and 4/6 [66.7%] studies, respectively; rating = ++). Strength/power was associated with sports participation in 12/16 [75.0%] studies and active transport in 3/6 [50.0%] studies, resulting in ratings of 'positive' (+) and 'inconsistent' (?), respectively. An insufficient number of studies remained after excluding those with a high risk of bias, and the summary associations were therefore unchanged.

3.3.2 Local muscular endurance

Muscular endurance was positively associated with physical activity in 37/53 (69.8%) studies, and in 7/14 (50.0%) studies after accounting for risk of bias (Table 2). Consequently, the association was downgraded from 'positive' (+) to 'inconsistent' (?). Again, when statistically significant associations were reported, they were predominantly weak to moderate. For objectively measured physical activity, the proportion of studies showing a positive association remained the same after excluding high risk of bias studies and was classified as 'consistent positive' (3/5 [60.0%] studies; rating = ++). Accounting for risk of bias weakened the association with self-reported physical activity, which was downgraded to 'inconsistent' (4/9 [44.4%] studies; rating = ?). Eight studies captured accelerometer-determined physical activity intensity. There was evidence for 'no association' between muscular endurance and MPA (1/4 [25.0%] studies; rating = 0) and a 'positive' association with VPA (4/5

[80.0%] studies, rating = +). There was little support for a positive association between muscular endurance and LPA (1/3 [33.3%] studies), but the small number of available studies resulted in a rating of ‘uncertain’ (?). Sports participation and active transport were positively associated with muscular endurance in 10/12 (83.3%) and 2/4 (50.0%) studies, resulting in ‘positive’ (+) and ‘inconsistent’ (?) ratings, respectively. Too few studies remained after accounting for risk of bias and the summary associations were therefore unchanged.

3.4 Muscular fitness and sedentary behaviors

In total, 25/87 (28.7%) studies examined associations between MF and sedentary behaviors, of which 23/25 (92.0%) were cross-sectional and two were longitudinal. Strength/power was assessed in 19/25 (76.0%) studies, and local muscular endurance was assessed in 14/25 (56.0%) studies. Only one of the two longitudinal studies assessed the longitudinal relationship between MF and sedentary behavior, whereas the other only examined the cross-sectional relationship.

3.4.1 Maximal strength/power

Overall, strength/power was inversely associated with sedentary behaviors in 8/19 (42.1%) studies, and 2/7 (28.6%) studies after excluding those with a high risk of bias (Table 1). The association was therefore downgraded from ‘inconsistent’ (?) to ‘no association’ (0). The one longitudinal analysis showed baseline TV viewing was inversely associated with follow-up strength/power, and increases in TV viewing were associated with poorer strength/power at follow-up [(60)]. Most studies used self-report measures of sedentary behavior, and most of these assessed screen-based sedentary behavior (e.g., TV viewing, computer/video game use, and/or total screen-time). Conversely, 5/19 (26.3%) studies measured sedentary time objectively using accelerometers. Strength/power was associated with objectively assessed and self-reported sedentary time in 2/5 (40.0%) and 6/14 (42.9%) studies, respectively, and the rating was unchanged after accounting for risk of bias (rating = ? for both). Similarly, there was mixed support for associations with ‘TV viewing’ and ‘computer/video game use’ with 3/8 (37.5%) and 2/5 (40.0%) studies reporting significant associations, respectively (rating = ? for both).

3.4.2 Local muscular endurance

Overall, muscular endurance was associated with sedentary behaviors in 7/15 (46.7%) studies (Table 2). An insufficient number of studies remained after excluding those with a high risk of bias, resulting in the association being classified as 'inconsistent' (?). When separated by measurement method, muscular endurance was associated with objectively measured sedentary time in 1/4 (25.0%) studies (rating = 0), and self-reported sedentary behaviors in 6/11 (54.5%) studies (rating = ?). Few studies remained after excluding those with a high risk of bias, and the summary associations were therefore unchanged. Of the studies using self-report measures, 2/6 (33.3%) reported significant associations with 'TV viewing', and 2/5 (40.0%) reported significant associations with 'computer/video game use'. Consequently, the associations for both sub-domains of recreational screen-time were classified as 'inconsistent' (?).

3.5 Muscular fitness and sleep

Two of 87 (2.3%) studies examined associations between MF and sleep, both of which were cross-sectional in design (Table 1). Both studies assessed associations between sleep and strength/power, and reported no significant associations. Despite this, the small number of available studies resulted in the association between strength/power and sleep being classified as 'uncertain' (?).

3.6 Associations according to specific MF measures

As shown in Table 3, physical activity was most consistently associated with performance in the standing long jump (17/25 [68.0%]) and push-up (9/12 [75.0%]) tests, and also with composite indices of MF (10/13 [76.9%]). Conversely, associations with grip strength (15/28 [53.6%]) and sit-up/curl-up (15/28 [53.4%]) performance were equivocal. For sedentary behaviour, no major differences in conclusions were found when examining specific MF measures, with most measures suggesting an 'inconsistent' association. The standing long jump (4/8 [50.0%] studies) and MF indices (2/4 [50.0%]) both showed the highest proportion of significant associations, whereas grip strength (3/9 [33.3%] studies) and push-ups (0/3 [0.0%] studies) showed the lowest. Only one of the two studies examining MF and sleep used common measures (i.e., grip strength and standing long jump), and neither of these showed a significant association.

4 DISCUSSION

The aim of the present review was to evaluate the evidence for associations between MF and physical activity, sedentary behaviors and sleep in children and adolescents. Notably, we found consistent evidence for a positive association between MF and physical activity, particularly for objectively assessed VPA and sports participation. Conversely, associations between MF and both objectively assessed and self-reported sedentary behaviors were inconsistent. Only two studies examined associations between MF and sleep, limiting our ability to conclude on this association.

Overall, we found consistent evidence for a positive association between physical activity and strength/power, and mixed evidence for a positive association with muscular endurance. However, when limited to studies using objective measures (e.g. accelerometers, pedometers, and heart rate monitoring), consistent evidence for a positive association was found for both components of MF. We can therefore conclude with confidence that more active children and adolescents demonstrate greater strength/power and local muscular endurance. However, it must also be recognised the magnitude of associations were generally weak to moderate [(61)], and caution should be taken not to exaggerate the strength of associations. Our findings are consistent with those of an earlier systematic review by Poitras and colleagues [(62)], and those of the 2018 Physical Activity Guidelines Advisory Committee (PAGAC) scientific report [(63)]. However, the present review extends upon these findings by reporting on the independent (rather than combined) associations with distinct components of MF (i.e., strength/power and muscular endurance). In addition, we provide a more comprehensive summary of the extant literature, by including studies using both self-report and objective measures (i.e., 77 studies vs 10 studies by Poitras et al. [(62)]).

A key finding from the present review was the consistent positive association found between objectively measured physical activity and both MF components. Importantly, excluding studies with a high risk of bias reinforced these findings. Of all the associations reported, VPA was found to be the most consistently associated with MF, whereas consistent evidence for an association with MVPA was only found for strength/power. Conversely, there was no support for a positive association between LPA and MPA with either MF component. This finding differs from that found previously for CRF, with systematic review evidence suggesting MPA may be sufficient for improving or maintaining CRF in school-aged children and adolescents [(62)]. Although VPA also shows the strongest association with CRF [(64)] our findings suggest VPA may not only be ideal but in fact necessary for developing MF.

This finding is illustrated most clearly by Martinez-Gomez et al. [(28)], who found no significant differences in MF between resistance training adolescents and their non-trained peers in the highest tertile of VPA. Conversely, adolescents in the bottom two tertiles of VPA did have significantly lower MF [(28)]. This indicates there is something about VPA in particular (rather than other PA intensities) that might support the development of MF. Given VPA in essence reflects a higher degree of work per unit time, one possible explanation for this finding might be neural adaptations in response to VPA that lead to greater motor-unit recruitment and/or synchronisation [(65)]. This said, VPA might also induce adaptations that impact upon the metabolic capacity of muscle cells, which subsequently influences musculoskeletal functioning [(65)]. Of note, past research has shown independent and additive effects of MF and CRF on health in young people [(66, 67)], suggesting these fitness components influence health status via unique physiological pathways. Considering physical activity intensity has differing associations with CRF and MF (as noted above), the strong relationship between VPA and health outcomes reported in past research [(68, 69)] may in part be explained by the additive effect of VPA on MF. Although speculative, this argument has implications for youth physical activity promotion, which we suggest should further emphasize the importance of regular participation in activities of vigorous intensity (e.g., running, fast cycling, organized sports such as basketball or football, circuit training, high-intensity interval training etc).

Although objective measures of physical activity are considered less prone to bias [(70)], they do not enable the assessment of physical activity ‘type’. Consequently, self-report measures remain a valuable tool for understanding how different physical activity contexts relate to health outcomes such as MF [(71)]. We found evidence for a positive association between sports participation and both MF components. While sport alone may not be sufficient for young people to meet daily physical activity targets [72], organised sports nonetheless provide an important opportunity to engage in MVPA on a regular basis [73]. Indeed, prior evidence shows sports participants accumulate more MVPA than their non-sporting peers [74, 75] and also demonstrate higher CRF [75]. Our findings suggest sports participation is also important for muscular development during the growing years. However, given most included studies were cross-sectional, bi-directionality is also possible. For example, strength, power and muscular endurance are important predictors of performance in many organised sports [76], and youth with greater MF might experience greater success and enjoyment in sport resulting in sustained participation. However, it is plausible this association is driven by sport naturally facilitating greater participation in VPA or (depending on the sport) activity that requires muscular force (e.g., jumping, tackling, and sprinting). As noted previously for VPA, participation in sports likely stimulates physiological adaptations that result in, among other things, greater MF.

Unlike for sports participation, the association between MF and active transport (i.e., walking/cycling) was equivocal with 50% of studies reporting a positive association for both MF components. Notably, our findings provide an important update to an earlier review of active transport and health-related fitness in youth, which only located one study that assessed MF [77]. In the present review, six studies explored the link between active transport and strength/power and four studies examined associations with muscular endurance. Despite an increase in the number of studies examining this relationship, the association between active transport and MF remains unclear. When positive associations were observed, they tended to be for comparisons between passive travellers and cyclists rather than with walkers, which is consistent with earlier findings for CRF [77]. For example, Cohen et al. [26] reported differences in grip strength between cyclists and passive travellers, whereas no differences in MF were seen for walkers in adjusted analyses. Given walking is considered a light-to-moderate intensity activity [78], it is not surprising to see a lack of association with MF. Conversely, research with adults shows cycling has a greater physiological demand than walking [79], and the positive impact of habitual cycling on MF is therefore more plausible. Indeed, among a sample of nearly 1700 schoolchildren, Østergaard et al. [80] reported higher CRF and MF among cyclists compared with both passive travellers and walkers.

Interestingly, associations between physical activity and MF were somewhat dependent on the MF measure used, with the standing long jump, push-ups, and composite MF indices showing the most consistent associations. Conversely, handgrip dynamometry and sit-up/curl-up tests showed less consistent associations, and conclusions based on these tests alone would suggest the association between MF and physical activity is uncertain. This finding has meaningful implications for the field, considering these two tests are commonly used, and grip strength in particular is considered one of the most valid field-based MF tests [7]. It should be noted that most included studies expressed grip strength in absolute terms, rather than relative to body weight, and prior research has found that overweight/obese (and presumably less active) children and adolescents have greater grip strength[4]. Of note, Edelson et al. [30] found significant associations between relative grip strength and self-reported physical activity, but not absolute grip strength, suggesting that one's strength relative to body mass is the more important factor. Alternatively, it may be that absolute grip strength is still an important marker of health, but is simply less relevant to physical activity as typical youth activities may not stimulate grip strength adaptations, which would make this a sub-optimal marker of physical activity exposure. Regardless, researchers should continue to explore how associations vary when comparing absolute grip strength and relative values that account for body mass, ideally using accepted allometric scaling techniques [81].

Another key finding was the lack of a consistent association between MF and sedentary behaviors, which was consistent across measurement approaches (i.e., objective and self-report) and across different MF tests. Despite evidence supporting the independent health impacts of excessive sedentary time in adults [82], the same has not been demonstrated for children and adolescents [83, 84]. Historically, sedentary behaviors were thought to displace time youth would otherwise spend being physically active [85], leading some to hypothesize an inverse relationship with health-related fitness. However, meta-analytic evidence shows the association between sedentary time and physical activity in young people is at best weak [86], undermining the displacement hypothesis. In a 2016 review, Cliff and colleagues [83] concluded there was no association between CRF and objectively measured sedentary time in children and adolescents following adjustment for MVPA. In the present review, three included studies [60, 87, 88] adjusted for physical activity in their analyses, two of which [60, 87] reported significant independent associations with MF, albeit that in one case this was dependent on the MF test used [87]. Conversely, the weak association between pre-school children's grip strength and objectively assessed sedentary time reported by Leppänen et al. [88] was attenuated following adjustment for VPA. In another systematic review, Carson and colleagues [31] reported mixed findings for associations between MF and both objectively and parent/self-reported sedentary time, but only four studies were located and findings for measures of strength/power and muscular endurance were combined. Our review therefore provides a novel contribution to the literature, and supports the view that sedentary time is likely not meaningfully linked with strength/power or muscular endurance in children and adolescents.

Due to an insufficient number of available studies, the association between MF and sleep was considered uncertain. Thivel et at. [89] found no significant associations between strength/power and children's sleep duration, bed time, or wake time. Similarly, Zaquout et al. [90] found no statistically significant associations between strength/power and total sleep duration among a large sample of European children. While both studies reported null findings, more high quality research exploring this relationship is required before a clear conclusion can be reached. For example, we located no studies examining the association between sleep characteristics and muscular endurance. Of note, studies using isotemporal substitution techniques that account for the interdependence of physical activity, sedentary behaviors and sleep have recently appeared in the literature [91]. In the absence of experimental evidence, these studies might be well suited to exploring the impact of sleep time on MF, given any benefits from increasing (or reducing) sleep time may depend on how and from where the additional time is reallocated (e.g., sedentary time vs MVPA time). Finally, the impact of poor sleep quality on MF should also be examined in future research, considering the quality of sleep has meaningful associations with other health outcomes, independent of sleep duration [92].

Strengths of the present review include the comprehensive literature search (i.e., >16,000 search results), consideration of risk of bias in the quantitative synthesis, and organisation of study findings according to distinct domains and measures of MF, which has been a limitation of past research [(7)]. In addition, the inclusion of self-report and objective measures enabled a broad examination of the range of associations between MF and physical activity, sedentary behaviors and sleep (i.e., by measurement approach, type of health behavior, and activity intensity). Such an approach provides practitioners and researchers with a more comprehensive summary of the extant literature, which may be of value for the design and delivery of future health promotion interventions.

There are also some limitations that must be noted. First, our findings must be considered in light of the high risk of bias of included studies. For example, only four out of 87 studies included in this review were classified as having a low risk of bias, whereas two thirds were considered to have a high risk of bias. Second, the vast majority of included studies were cross-sectional, meaning our ability to conclude on the causal direction of the associations is limited. Third, while we organised study findings according to the MF components assessed, we did not compare associations across specific body regions (e.g., lower body, upper body, abdominal/core) or muscle groups, albeit this was somewhat indirectly achieved by examining associations according to the most common MF measures. Fourth, the vast majority of studies did not use criterion measures of maximal strength/power and local muscular endurance, which although understandable given feasibility constraints also means that many of the associations described herein should be interpreted cautiously (i.e., in light of the questionable criterion validity of many field-based MF tests). Finally, despite including studies with pre-school aged children (~3-5 years), few relevant studies were located, meaning our findings are not generalizable to this group.

4.1 Future research directions

The findings of this review highlight a number of potential areas for future research. Research with pre-school aged youth is needed, as this population remains highly under-represented. With regards to physical activity, additional well-conducted longitudinal and experimental studies that explore the impact of improving MF on subsequent physical activity behavior are warranted. In addition, high quality studies that explore associations between MF and other context- (e.g., outdoor play) or time-specific (e.g., after-school) physical activity would be of value. With regards to sedentary behaviors, further research exploring associations between contemporary electronic screen-media (e.g., tablet/smartphone use, internet gaming) and MF would be of interest, and these studies would ideally adjust for the confounding effect of physical activity. Finally, there is a clear need for research examining the associations between child and adolescent sleep characteristics (e.g., sleep duration and sleep quality) and MF, as there is currently very little research available on this topic.

5 CONCLUSIONS

We conclude there is consistent evidence supporting a positive association between physical activity and MF in children and adolescents, albeit that effect sizes were generally weak to moderate. Of the range of physical activity variables assessed, we found the strongest support for objectively assessed vigorous physical activity and organised sports participation. Conversely, there is little support for a positive association with light or moderate intensity activity, and it remains unclear whether habitual active transport is associated with higher MF. Secondly, the evidence for an inverse association between sedentary behavior and MF is limited, and our findings suggest a meaningful association is unlikely. Finally, there is insufficient evidence to conclude on the link between sleep and MF, highlighting a gap for future research.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Table 1. Summary of findings for studies examining associations between maximal strength/power and health behaviors

Behaviors	Associated with MF component	Not associated with MF component	Summary coding			
			n/N (%)[a]	Association[b]	n/N (%)[c]	Summary association[b, d]
Physical activity	(8, 26-28, 30, 48, 52, 56, 58, 80, 88, 93-124)	(47, 49-51, 53-55, 57, 59, 90, 125-136)	43/65 (66.2)	+	16/26 (61.5)	++
Objective physical activity	(28, 88, 99, 106, 111-113, 119)	(47, 90, 125, 126, 129, 130, 134)	8/15 (53.3)	?	8/11 (72.7)	++
Moderate-to-vigorous intensity	(88, 112, 113, 119)	(28, 90, 111)	4/7 (57.1)	?	4/6 (66.7)	++
Vigorous intensity	(28, 88, 99, 111-113, 119)	(125, 126, 134)	7/10 (70.0)	+	7/9 (77.8)	++
Moderate intensity	(99)	(28, 88, 111-113, 125, 126, 134)	1/9 (11.1)	0	1/8 (12.5)	0
Light intensity	(99)	(28, 113, 119, 125)	1/5 (20.0)	0	1/5 (20)	0
Self-reported physical activity	(8, 26, 27, 30, 48, 52, 56, 58, 80, 93-98, 100-105, 107-110, 112, 114-118, 120-124)	(49-51, 53-55, 57, 59, 127, 128, 131-133, 135, 136)	36/51 (70.6)	+	9/16 (56.3)	?
Sports participation	(27, 93-97, 103, 104, 107, 108, 117, 124)	(55, 57, 98, 132)	12/16 (75.0)	+	2/3 (66.7)	+
Active transport	(26, 80, 122)	(49, 54, 135)	3/6 (50.0)	?	1/3 (33.3)	?
Sedentary behaviors	(27, 29, 30, 60, 97, 99, 119, 137)	(28, 56, 88, 96, 98, 113, 120, 132, 138-140)	8/19 (42.1)	?	2/7 (28.6)	0
Objective sedentary time	(99, 119)	(28, 88, 113)	2/5 (40.0)	?	2/5 (40.0)	?
Self-reported sedentary time	(27, 29, 30, 60, 97, 137)	(56, 96, 98, 120, 132, 138-140)	6/14 (42.9)	?	0/2 (0.0)	?
TV viewing	(27, 30, 60)	(29, 96, 138-140)	3/8 (37.5)	?	0/1 (0.0)	?
Computer/video games	(29, 97)	(30, 96, 98)	2/5 (40.0)	?	0/1 (0.0)	?
Sleep		(89, 90)	0/2 (0.0)	?	0/1 (0.0)	?

Note. MF = muscular fitness; TV = television.

[a] Total number of studies reporting a statistically significant association (n) / all studies examining associations between strength/power and behavior (N).

[b] 0 = no evidence for association; ? = association is inconsistent or uncertain; + = positive association; ++ = consistent positive association.

[c] Total number of studies reporting a statistically significant association (n) / all studies examining associations between strength/power and behavior (N), after excluding high risk of bias studies.

[d] Additional coding conducted only if ≥ 4 studies remained after excluding high risk of bias studies.

Table 2. Summary of findings for studies examining associations between local muscular endurance and health behaviors

Behaviors	Associated with MF component	Not associated with MF component	Summary coding			
			n/N (%)[a]	Association[b]	n/N (%)[c]	Summary association[b,d]
Physical activity	(28, 30, 50, 52, 55, 58, 59, 80, 87, 95-100, 102-106, 109, 110, 116, 118, 120, 121, 124, 131, 132, 134, 135, 141-146)	(8, 44, 47, 49, 51, 54, 57, 115, 125, 127, 130, 133, 147-150)	37/53 (69.8)	+	7/14 (50.0)	?
Objective physical activity	(28, 87, 99, 106, 134, 146, 150)	(47, 125, 130)	6/10 (60.0)	+	3/5 (60.0)	++
Moderate-to-vigorous intensity	(87)	(28, 146)	1/3 (33.3)	?	0/1 (0.0)	?
Vigorous intensity	(28, 99, 134, 146)	(125)	4/5 (80.0)	+	2/3 (66.7)	+
Moderate intensity	(99)	(28, 125, 134)	1/4 (25.0)	0	1/3 (33.3)	0
Light intensity	(99)	(28, 125)	1/3 (33.3)	?	1/3 (33.3)	?
Self-reported physical activity	(30, 50, 52, 55, 58, 59, 80, 95-98, 100, 102-105, 109, 110, 116, 118, 120, 121, 124, 131, 132, 135, 141-145)	(8, 44, 49, 51, 54, 57, 115, 127, 133, 147-150)	31/44 (70.5)	+	4/9 (44.4)	?
Sports participation	(55, 95-98, 103, 104, 124, 132, 141)	(44, 57)	10/12 (83.3)	+	2/2 (100)	+
Active transport	(80, 135)	(49, 54)	2/4 (50.0)	?	0/2 (0.0)	?
Sedentary behaviors	(30, 97-99, 120, 145, 151)	(28, 87, 96, 132, 140, 146, 152, 153)	7/15 (46.7)	?	1/3 (33.3)	?
Objective sedentary time	(99)	(28, 87, 146)	1/4 (25.0)	0	1/2 (50.0)	0
Self-reported sedentary time	(30, 97, 98, 120, 145, 151)	(96, 132, 140, 152, 153)	6/11 (54.5)	?	0/1 (0.0)	?
TV viewing	(30, 145)	(96, 140, 152, 153)	2/6 (33.3)	?	0/1 (0.0)	?
Computer/video games	(97, 98)	(30, 96, 145)	2/5 (40.0)	?	0/1 (0.0)	?

Note. MF = muscular fitness; TV = television.

[a] Total number of studies reporting a statistically significant association (n) / all studies examining associations between local muscular endurance and behavior (N).

[b] 0 = no evidence for association; ? = association is inconsistent or uncertain; + = positive association; ++ = consistent positive association.

[c] Total number of studies reporting a statistically significant association (n) / all studies examining associations between local muscular endurance and behavior (N), after excluding high risk of bias studies.

[d] Additional coding conducted only if ≥ 4 studies remained after excluding high risk of bias studies.

Table 3. Summary of findings for associations between health behaviors and the most commonly used MF measures

Behaviors/MF measures	Associated with behavior	Not associated with behavior	Summary coding	
			n/N (%)[c]	Association[d]
Physical activity				
Handgrip strength[a]	(8, 26, 27, 30, 88, 93, 95, 97, 101, 106, 109, 119, 120, 123, 132)	(50, 53-55, 58, 90, 100, 113, 115, 122, 125, 131, 136)	15/28 (53.6)	?
Sit-up / curl-up[b]	(50, 55, 58, 95, 97, 98, 105, 109, 118, 120, 132, 135, 143, 144, 146)	(8, 49, 54, 57, 80, 87, 115, 125, 130, 133, 147-149)	15/28 (53.4)	?
Standing long jump[a]	(27, 58, 80, 88, 95, 97, 98, 100, 102, 105, 107, 109, 113, 115, 117, 119, 120, 122)	(50, 53, 90, 125, 128, 133, 135)	18/25 (72.0)	+
Push-up[b]	(50, 87, 102, 103, 116, 131, 134, 141, 143)	(44, 146, 147)	9/12 (75.0)	+
MF index[a,b]	(28, 96, 99, 104, 110-112, 121, 124, 142)	(51, 127, 150)	10/13 (76.9)	+
Sedentary behaviors				
Handgrip strength[a]	(30, 113, 137)	(88, 97, 119, 120, 132, 139)	3/9 (33.3)	0
Sit-up / curl-up[b]	(87, 97, 98, 120)	(132, 140, 146, 152, 153)	4/9 (44.4)	?
Standing long jump[a]	(27, 60, 97, 119)	(88, 98, 113, 120)	4/8 (50.0)	?
Push-up[b]		(87, 146, 153)	0/3 (0.0)	?
MF index[a,b]	(99, 151)	(28, 96)	2/4 (50.0)	?
Sleep				
Handgrip strength[a]		(90)	0/1	?
Standing long jump[a]		(90)	0/1	?

Note. MF = muscular fitness

[a] Test evaluates maximal strength/power

[b] Test evaluates local muscular endurance

[c] Total number of studies reporting a statistically significant association (n) / all studies examining associations between MF test and behavior (N).

[d] 0 = no evidence for association; ? = association is inconsistent or uncertain; + = positive association.

555 **Table 4.** Risk of bias for included studies

Reference	1. Study design	2. Selection bias	3. Sample description	4. Valid fitness measure	5. Valid behavioral measure	6. Confounder adjustment	Global rating
Afghani et al. (2003)(93)	High	Moderate	Moderate	Moderate	High	High	High
Andersen et al. (1994)(57)	Moderate	Moderate	Moderate	Moderate	High	High	High
Andersen et al. (2009)(135)	High	Low	Moderate	Moderate	High	High	High
Ara et al. (2004)(94)	High	Low	Moderate	Low	High	Moderate	High
Ara et al. (2007)(95)	High	Low	Moderate	Moderate	High	High	High
Baquet et al. (2006)(58)	Moderate	High	Moderate	Moderate	High	Moderate	Moderate
Armstrong et al. (1998)(152)	High	Moderate	Moderate	High	High	High	High
Barnekow-Bergkvist et al. (2001)(49)	Moderate	Low	Moderate	Low	High	Low	Moderate
Beets & Pitetti (2005)(141)	High	High	Moderate	High	High	High	High
Blaes et al. (2011)(125)	High	High	Moderate	Moderate	Low	Moderate	Moderate
Buchheit et al. (2007)(126)	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate
Castelli & Valley (2007)(147)	High	High	Moderate	High	Moderate	Low	High

Chan et al. (2003)[8]	High	Moderate	Moderate	Moderate	High	High	High
Ciesla et al. (2014a)[97]	High	Low	Moderate	Moderate	High	High	High
Ciesla (2014b)[98]	High	Low	Moderate	Moderate	High	High	High
Cohen et al. (2014)[26]	High	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Day et al. (2015)[55]	Moderate	High	Moderate	Moderate	High	Moderate	Moderate
De Baere et al. (2016)[99]	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate
de Souza et al. (2014)[50]	Moderate	Moderate	Moderate	Moderate	Moderate	High	Moderate
Edelson et al. (2016)[30]	High	Low	Moderate	Moderate	High	Moderate	High
Eiholzer et al. (2010)[47]	Low	High	Moderate	Low	Low	Moderate	Low
Esmaeilzadeh (2015)[100]	High	Moderate	Moderate	Moderate	Moderate	High	High
Fang et al. (2016)[146]	High	High	Moderate	High	Moderate	High	High
Fitzpatrick et al. (2012)[60]	Moderate	Low	Low	Moderate	Moderate	Moderate	Low
Foo et al. (2007)[101]	High	High	Moderate	Moderate	Moderate	Moderate	Moderate
Garcia-Artero et al. (2007)[127]	High	High	Moderate	Moderate	Moderate	Moderate	Moderate

Gonzalez-Suarez & Grimmer-Somers (2011)[128]	High	Moderate	Moderate	Moderate	Moderate	High	High
Grøntved et al. (2013)[29]	High	Low	Low	Low	High	Low	High
Grund et al. (2000)[129]	High	High	Moderate	Moderate	Moderate	High	High
Grund et al. (2001)[138]	High	Moderate	Moderate	Moderate	High	High	High
Gu et al. (2016)[150]	High	High	Moderate	High	Moderate	High	High
Hands et al. (2009)[130]	High	High	Moderate	High	Low	High	High
Haugen et al. (2013)[102]	High	High	Moderate	Moderate	Low	High	High
Hoffman et al. (2005)[103]	High	High	Moderate	High	High	High	High
Huang & Malina (2002)[148]	High	Moderate	Moderate	High	High	Moderate	High
Huotari et al. (2010)[104]	High	Low	Moderate	Moderate	High	Moderate	High
Huotari et al. (2011)[51]	Moderate	Low	Moderate	Moderate	High	Moderate	Moderate
Inskip et al. (2012)[139]	High	High	Low	Moderate	High	Moderate	High
Kalantari & Esmaeilzadeh (2016)[131]	High	Moderate	Moderate	Moderate	Moderate	High	High
Karppanen et al. (2012)[105]	High	High	Moderate	Moderate	Moderate	High	High

Katzmarzyk et al. (1998)[140]	High	High	Moderate	Low	Moderate	Moderate	Moderate
Kemper et al. (2001)[52]	Moderate	High	High	High	High	Low	High
Khoo & Al-Shamli (2012)[132]	High	Low	Moderate	Moderate	High	High	High
Larouche et al. (2014)[106]	High	High	High	Moderate	Moderate	Low	Moderate
Leppänen et al. (2016)[88]	High	Low	Moderate	Moderate	Low	Low	Moderate
Lo et al. (2017)[133]	High	High	Moderate	Moderate	High	High	High
Loko et al. (2003)[107]	High	High	High	Moderate	High	High	High
Lopes et al. (2011)[53]	Moderate	High	Moderate	Moderate	Moderate	Low	Low
Macfarlane et al. (2008)[108]	High	High	Moderate	High	Low	High	High
Maciulevičienė et al. (2013)[134]	High	Moderate	Moderate	High	Low	High	High
Marques et al. (2015)[87]	High	Low	Moderate	High	Low	Moderate	High
Marta et al. (2011)[109]	High	High	Moderate	Moderate	High	High	High
Marsh & Johnson (1994)[110]	High	Low	Moderate	Moderate	High	High	High
Martinez-Gomez et al. (2011)[28]	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate

Martinez-Gomez et al. (2012a)[111]	High	High	Moderate	Moderate	Low	Moderate	Moderate
Martinez-Gomez et al. (2012b)[112]	High	Moderate	Moderate	Moderate	Low	Moderate	Moderate
Minck et al. (2000)[59]	Moderate	Moderate	Moderate	High	High	Moderate	High
Moliner-Urdiales et al. (2010)[113]	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Morrow et al. (2013)[142]	High	High	Low	High	High	Moderate	High
Mota et al. (2010)[143]	High	High	Moderate	High	High	Moderate	High
Newcomer et al. (1997)[56]	Moderate	High	Moderate	Low	High	Moderate	Moderate
Nordstrom et al. (1996)[114]	High	High	Moderate	Low	High	High	High
Østergaard et al. (2013)[80]	High	Low	Moderate	Moderate	High	Moderate	High
Peterson et al. (2014)[136]	High	High	Moderate	Moderate	Moderate	High	High
Pyky et al. (2015)[137]	High	High	Low	Moderate	High	High	High
Raudsepp & Jurimae (1996)[115]	High	High	Moderate	Moderate	Moderate	Moderate	Moderate
Ruiz et al. (2010)[27]	High	Low	High	Moderate	High	Low	High
Rutkauskaitė et al. (2011)[116]	High	High	Moderate	High	Moderate	High	High

Sacchetti et al. (2012)[117]	High	Low	Moderate	Moderate	Moderate	High	High
Sallis et al. (1993)[144]	High	High	Moderate	High	Moderate	Moderate	High
Salminen et al. (1993)[118]	High	Moderate	Moderate	High	High	High	High
Shriver et al. (2011)[149]	High	Moderate	Moderate	High	Moderate	High	High
Smith et al. (2010)[145]	High	High	Moderate	High	High	Moderate	High
Stenevi-Lundgren et al. (2009)[48]	Low	High	Moderate	Low	High	Moderate	Moderate
Tanaka et al. (2012)[119]	High	High	Moderate	Moderate	Moderate	Moderate	Moderate
Thivel et al. (2015)[89]	High	High	Moderate	High	Moderate	High	High
Tian et al. (2014)[120]	High	High	Moderate	Moderate	Moderate	High	High
Tittlbach et al. (2011)[121]	High	Low	Moderate	Moderate	High	Moderate	High
Trudeau et al. (2009)[54]	Moderate	High	High	Moderate	High	Moderate	Moderate
Tucker et al. (2014)[151]	High	High	Moderate	High	Moderate	Moderate	High
Tucker & Hagar (1996)[153]	High	High	Moderate	High	High	High	High
Valter Filho et al. (2014)[96]	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Villa-Gonzalez et al. (2015)[122]	High	High	Moderate	Moderate	High	Moderate	High
Voss et al. (2014)[123]	High	High	Low	Moderate	Moderate	Moderate	Moderate
Woods et al. (1992)[44]	High	High	Moderate	High	High	High	High
Zahner et al. (2009)[124]	High	Low	Moderate	High	High	Moderate	High
Zaqout et al. (2016)[90]	Moderate	Moderate	Low	Moderate	Moderate	Moderate	Low

Note. Global rating generated based on criteria 1, 4, 5, and 6 as follows: "low" when 0 items rated as high risk of bias, “moderate” when 1 component rated as high risk of bias, and “high” when ≥ 2 components rated as high risk of bias.

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