

**Review Article**

# Muscle Strength and Fitness in Pediatric Obesity: a Systematic Review from the European Childhood Obesity Group

David Thivel<sup>a, b, c</sup> Susanne Ring-Dimitriou<sup>c, d</sup> Daniel Weghuber<sup>c, e, f</sup>  
Marie-Laure Frelut<sup>c, g</sup> Grace O'Malley<sup>c, h</sup>

<sup>a</sup>Laboratory of the Metabolic Adaptations to Exercise under Physiological and Pathological Conditions (AME2P), UE3533, Clermont Auvergne University, Clermont-Ferrand, France;

<sup>b</sup>Auvergne Regional Center for Human Nutrition (CRNH), Clermont-Ferrand, France; <sup>c</sup>European Childhood Obesity Group, Brussels, Belgium; <sup>d</sup>Department of Sport Science and Kinesiology, Paris Lodron-University, Salzburg, Austria; <sup>e</sup>Department of Pediatrics, Paracelsus Medical University, Salzburg, Austria; <sup>f</sup>Obesity Research Unit, Paracelsus Medical University, Salzburg, Austria; <sup>g</sup>Pediatric Endocrinology department, Bicêtre Paris Sud University Hospital, Paris, France; <sup>h</sup>Physiotherapy Department, Temple Street Children's University Hospital, Temple Street, Dublin, Ireland

## Key Words

Children · Adolescents · Obesity · Strength · Power · Function · Musculoskeletal fitness · Field-testing

## Abstract

The increasing prevalence of paediatric obesity and related metabolic complications has been mainly associated with lower aerobic fitness while less is known regarding potential musculoskeletal impairments. The purpose of the present systematic review was to report the evidence regarding muscular fitness in children and adolescents with obesity. A systematic article search was conducted between November 2014 and June 2015 using MEDLINE, EMBASE, CINAHL psycINFO, SPORTDiscus and SocINDEX. Articles published in English and reporting results on muscle strength and muscular fitness in children and adolescents aged 6 to 18 years were eligible. Of 548 identified titles, 36 studies were included for analyses. While laboratory-based studies described higher absolute muscular fitness in youth with obesity compared with their lean peers, these differences are negated when corrected for body weight and lean mass, then supporting field-based investigations. All interventional studies reviewed led to improved muscular fitness in youth with obesity. Children and adolescents with obesity display impaired muscular fitness compared to healthy-weight peers, which seems mainly due to factors such as excessive body weight and increased inertia of the body. Our analysis also points out the lack of information regarding the role of age, maturation or sex in the current literature and reveals that routinely used field tests analysing overall daily muscular fitness in children with obesity provide satisfactory results when compared to laboratory-based data.

© 2016 S. Karger GmbH, Freiburg

PD Dr. David Thivel  
AME2P Laboratory, Bat Bio B. Campus Universitaire des Cezeaux  
UE3533, Clermont Auvergne University  
5 Impasse Amelie MURAT, TSA60026, CS60026, 63178 Aubiere Cedex, France  
thiveldavid@hotmail.com

## Introduction

The alarming worldwide development of paediatric overweight and obesity has become a major public health concern negatively affecting national health systems [1, 2]. The childhood obesity epidemic has been associated with obesogenic factors such as intake of energy-dense diets and low levels of physical activity [3], which favours impaired physical fitness [4–6]. Decreased overall physical fitness contributes to the development of obesity-related complications in childhood [7] and influences the risk of future chronic disease [8, 9]. A recent framework of recommended outcome measures for use in childhood obesity intervention research highlighted the importance of monitoring physical fitness [10]. Although cardio-respiratory fitness has long been considered as the primary factor supporting good health, musculoskeletal fitness is now recognised as a crucial component in maintaining overall health and fitness [11–13]. Limited data are available, however, concerning musculoskeletal fitness, and some authors have recently highlighted that more quality research is needed to clearly determine the role of musculoskeletal fitness in child and adolescent health [14]. In a recent systematic review and meta-analysis, Smith and collaborators [13] emphasised the potential physiological and psychological benefits associated with muscular fitness in children and adolescents. Their analysis revealed strong evidence for an inverse association between muscular fitness and adiposity (total and central), cardiovascular disease or metabolic risk factors; and a positive association with bone health and self-esteem [13]. Importantly, the relationships between muscular fitness and health benefits in youth have been shown to be independent of cardio-respiratory fitness and highlight the importance of considering both parameters of physical fitness [13].

Muscular fitness is mostly described in terms of muscle strength, defined as the ability to produce a force against a resistance, while muscle power or explosiveness is the rate at which the force can be generated. Muscle strength and more globally muscular fitness have important implications in daily living and are essential for performing activities of daily life. Youth who are overweight and obese have been shown to have a lower physical activity level compared to lean peers [15], and this can greatly affect their muscular fitness and in turn negatively impact overall physical fitness. Reduced levels of physical activity promote impairments in musculoskeletal fitness, which in turn may negatively influence participation in physical activity, thus initiating a vicious cycle. It is essential to assess musculoskeletal fitness and promote the prevention of impairments; however, the accurate examination of muscular fitness in children with obesity can be particularly challenging due to the child's body composition and dimensions.

While some recent papers focus on muscular fitness in the general paediatric population, we failed to find any reviews in those who are obese. Therefore, the aim of this review is to systematically examine the effect of obesity on muscular fitness in children and adolescents.

## Methods

This systematic review was conducted in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [16, 17]. The main objective of this systematic review was to describe the current available literature regarding muscle strength and muscular fitness in children and adolescents who are obese.

### *Study Eligibility*

#### *Inclusion Criteria*

Observational and interventional studies published in English in peer-reviewed journals were eligible for inclusion in the review if data (or part of the presented data) concerned muscle strength or performance in children and adolescents with obesity (<18 years).

#### *Exclusion Criteria*

All published, peer-reviewed studies were eligible for inclusion; no date limits were imposed, but due to feasibility studies in languages other than English or French were excluded. Studies were excluded if the mean age of participants was greater than 17.99 years or if the population was composed of children and adolescents not only presenting with obesity but with other functional diseases that were identified as confounding factors.

### *Data Source / Search Strategy*

The following electronic bibliographic databases were searched: MEDLINE, EMBASE, CINAHL psycINFO, SPORTDiscus and SocINDEX. All searches were conducted from January 2014 to March 2015. Each database search used the same key words to identify the specific population under study: 'child' OR adolescen\* AND obes\* OR weight'. 'Muscle strength', 'muscle power', 'muscle endurance', 'muscle function', 'physical fitness' and 'musculoskeletal fitness' were also used as specific key words. Titles and abstracts of potentially relevant articles were screened and full-text copies were obtained for articles meeting initial screening criteria. Full-text articles were screened in duplicate for inclusion in the review, and any discrepancies were agreed by consensus. All selected references were then extracted to Endnote software version X4 (Thompson Reuters; New, NY, USA).

### *Study Selection*

Papers were initially screened for inclusion based on the title, and two authors independently assessed the papers' eligibility. Each author coded papers as 'yes', 'no' or 'maybe' for eligibility. Subsequently, the abstracts were screened and eligibility confirmed whereby any disagreement regarding inclusion was discussed until a consensus was found among all co-authors.

### *Risk of Bias in Individual Studies*

Risk of bias was independently evaluated by two authors using the Cochrane risk of bias tool [18]. Risk of bias was assessed for selection bias, performance bias, detection bias, attrition bias and reporting bias. Any discrepancies in bias coding were resolved by a third reviewer. Studies were not excluded on the basis of risk of bias. This process is presented for each item in table 1.

**Table 1.** Study risk of bias

Study	Randomization procedure	Adequate description of the study sample (i.e., number of participants, mean age and sex);	Assessment/ reporting	Assessment of the potential benefit (i.e., validity/reliability of outcome reported and/or measurement procedure adequately described)	Adjustment for confounders	Total score/5
De Toia et al., 2009 [27]	0	1	1	1	0	3
Aucouturier et al., 2007 [34]	0	1	1	1	1	4
Thivel et al., 2011 [28]	1	1	1	1	1	5
Shang et al., 2010 [35]	1	1	1	1	0	4
Pongprapai et al., 1994 [29]	1	1	1	1	0	4
Castro-Pinero et al., 2009 [37]	1	1	1	1	0	4
McGuigan et al., 2009 [19]	0	1	1	1	1	4
Sgro et al., 2009 [20]	0	1	1	1	1	4
Andreasi et al., 2010 [39]	0	1	1	1	0	3
Dumith et al., 2010 [40]	1	1	1	1	0	4
Riddiford-Harland et al., 2006 [41]	1	0	1	1	0	4
Tokmakidis et al., 2006 [42]	0	1	1	1	0	4
Sacchetti et al., 2012 [43]	1	1	1	1	1	5
Lazzer et al., 2009 [30]	0	1	1	1	1	4
Dokic et al., 2013 [44]	0	1	1	1	0	3
Rauch et al., 2012 [52]	0	1	1	1	1	4
Dao et al., 2004 [21]	0	1	1	1	1	4
Huang and Malina, 2010 [45]	0	1	1	1	0	3
Poeta et al., 2012 [22]	0	1	1	1	0	3
Ward et al., 1997 [46]	0	1	1	1	0	3
Tsiros et al., 2012 [47]	0	1	1	1	1	4
Lau et al., 2004 [23]	1	1	1	1	0	4
Liao et al., 2013 [31]	1	1	1	1	0	4
Pienaar et al., 2013 [24]	0	1	1	1	0	3
O'Malley et al., 2012 [6]	0	1	1	1	0	3
Abdemoula et al., 2012 [48]	0	1	1	1	1	4
Duché et al., 2002 [32]	0	1	1	1	1	4
Karner-Resek et al., 2013 [25]	0	1	1	1	0	3
Lee et al., 2012 [26]	0	1	1	1	0	3
Deforche et al., 2003 [33]	1	1	1	1	0	4
Fogelholm et al., 2008 [50]	1	1	1	1	0	4
Blimkie et al., 1990 [51]	0	1	1	1	1	4
Tsang et al., 2010 [49]	1	1	1	1	0	4
Maffiuletti et al., 2008 [53]	0	1	1	1	1	4
Ceschia et al., 2015 [38]	0	1	1	1	1	4
Ervin et al., 2014 [36]	0	1	1	1	0	3

### *Data Collection*

Following the selection process all the included publications were collated in the EndNote reference management software. Then each author completed data extraction for the included papers. Any issue encountered by an author when extracting the data was discussed collectively, and a consensus was adopted to harmonise the extraction process. Data extracted from each article included basic study information (authors, publication date, title, physical parameter tested, design), population characteristics (sample size; age, gender, BMI, obesity definition), methods used and results.

### *Synthesis of the Results*

Tables were developed based on a-priori headings chosen collectively by the authors (reference, population, main outcome, methods, methods' reliability, intervention and comments). Studies were classified according to the age of participants (based on the youngest participant enrolled in each study).

## **Results**

The initial online database search identified a total of 548 records of which 432 were excluded after a first screening process. Subsequently, 80 publications were further excluded after consideration of the eligibility criteria, and finally by the end of the selection process 36 publications were included, all published between 1970 and 2015. Figure 1 illustrates this selection process.

### *Characteristics of Included Studies*

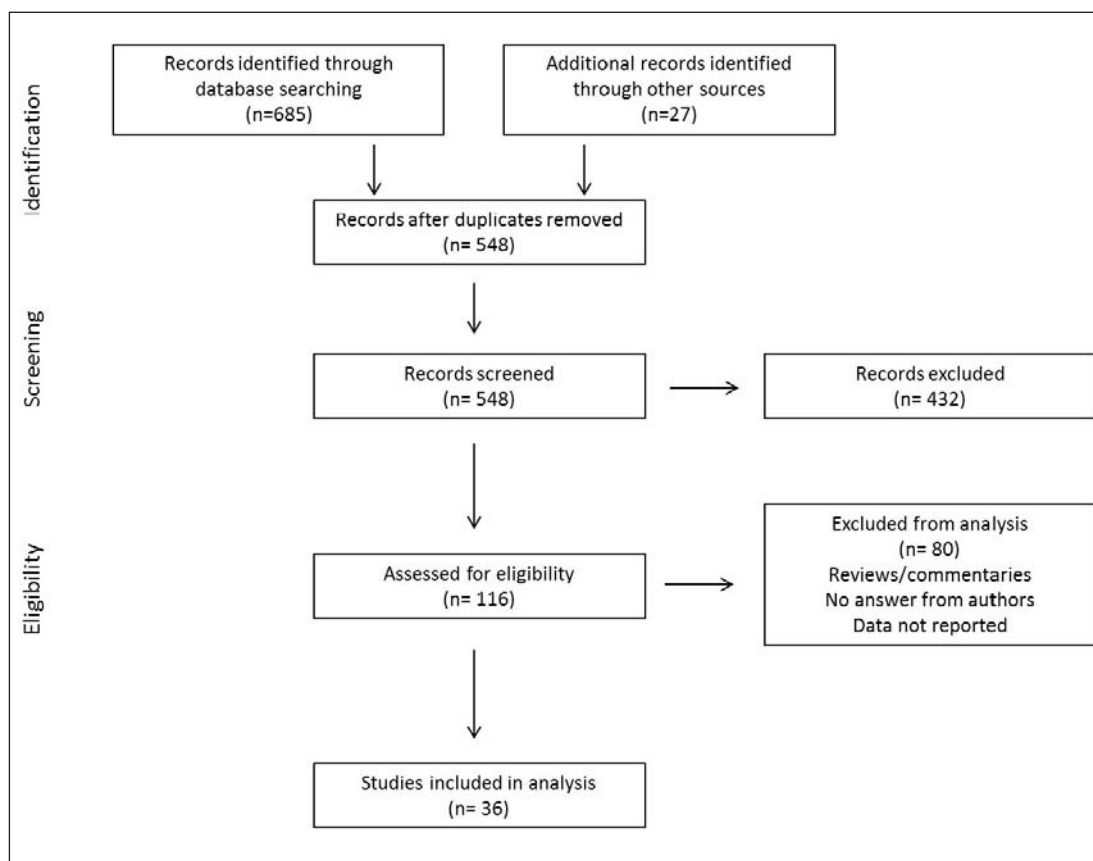
Included studies are presented in supplemental table 1 (available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=443687>) according to the participants' age ranging from 4.7 to 18 years. Nine of the 36 studies referenced in supplemental table 1 enrolled only children and adolescents who were obese and/or overweight [6, 19–26], and 27 compared weight status with healthy-weight and/or underweight subsamples.

Obesity was defined according to national curves in 8 studies [21, 27–33]; 22 used international cut-points [19, 20, 22, 24, 34–51], and 6 did not report the references used [6, 23, 25, 26, 52, 53].

Among the 36 included studies, 15 used objective methods to assess muscle strength and muscular fitness such as ergometers, dynamometers and/or force platforms [6, 21, 22, 25, 28, 30, 32–34, 46–48, 51–53], while in other studies field tests were completed.

Tests based on jump performances were mostly used to assess lower limb muscle strength, with the standing long jump employed in 12 studies [27, 31, 33, 35, 37, 38, 41–45]. To assess upper body strength, some studies used handgrip dynamometers [21, 22, 33, 36, 38], while indirect methods such as abdominal tests [22, 31, 39, 44, 45], push- and pull-ups [24, 36, 40, 41, 44] or medicine-ball throws [38, 40, 43] were more often used.

Nine studies were interventional trials [19–25, 28, 49], the other 27 were observational studies. The interventional studies consisted of exercise training lasting from 6 weeks [23], 8 weeks [19, 25], 12 weeks [22], 13 weeks [24] to 6 [28, 49] and 9 months [21]. Sgro et al. [20] compared in the same protocol 8- versus 16- versus 24-week programmes. One of the studies examined the effect of 1 session per week [49], one examined 2 sessions per week [28], five



**Fig. 1.** Flow chart presenting the screening and selection process.

instructed participants to train 3 times a week [19, 21–24], Karner [25] encouraged daily activities and Sgro and colleagues [20] failed to report the frequency of their training sessions. Though 5 of the studies described multidisciplinary programmes [21, 22, 24, 25, 28], 3 described resistance-only interventions [19, 20, 23] and 1 described a Kung-Fu-based training [49]. Importantly, Pienaar and colleagues [24] examined the effect of a home-based programme.

Of the 36 included studies, 33 assessed lower limb strength [6, 19–21, 23–38, 40–45, 47–53], 14 assessed upper limb strength [21–23, 24, 33, 36–38, 40, 41, 43, 44, 46, 49], and 9 specifically measured abdominal strength [22, 24, 31, 33, 36, 39, 44, 45, 50].

### *Results of Included Studies*

#### *Lower Limb Muscle Strength*

Using jump tests such as vertical jump, standing broad jump or standing long jump, 3 studies did not find any differences in performance between participants who were lean versus obese [27, 35, 38], 1 study observed higher performance in those who were obese [36], and 11 found reduced performances in those who were obese [31, 33, 37, 40–45, 50, 52]. Pongprapai and collaborators [29] observed better sit-up results in children who were obese compared with those who were lean.

Seven out of the 36 included studies observed higher lower limb muscle strength in those who were obese compared with lean subjects when expressed in absolute values [28, 30, 32, 34, 47, 48, 53]. Although Lazzer et al. [30] did not find differences between children who were lean versus those who were obese, when lower limb muscle strength was related to body mass, 6 studies observed lower results in the sample with obesity [28, 32, 34, 47, 48, 51]. Six studies observed similar results in those who were obese those who were lean when expressed according to lean mass [30, 32, 34, 47, 48, 53], while Thivel et al. [28] were the only authors to describe larger strength levels in those with obesity. Abdemoula and colleagues [48] were the only authors to report lower limb muscle strength scaled for skeletal muscle mass and observed higher results in those with obesity compared to lean participants. Finally, data were missing in two studies [26, 39].

#### *Upper Limb Muscle Strength*

Three studies using pull-ups observed lower performance in children with obesity [36, 40, 44], whereas Castro-Pinero and colleagues [37] observed similar results using push-ups. Ward et al. [46] found higher performance expressed in absolute values in those who were obese during a shoulder extension exercise; however, when expressed according to body mass, performances were lower in those who were obese and similar in both groups when expressed relative to fat-free mass. The same authors observed higher absolute results in obesity during an elbow extension exercise, but lower ones when expressed according to body mass or fat-free mass [46]. Using ball throw tests, 2 studies found similar results whatever the children's weight status was [37, 40], although two others found better performances in children with obesity [41, 43]. Finally, two studies described greater muscle strength in those with obesity compared to lean peers using handgrips (dynamometry) [33, 36] and one study found no difference [38].

#### *Abdominal Strength*

Five of the included observational studies that assessed abdominal strength found lower abdominal fitness in children and adolescents with obesity compared to their lean counterparts, with 2 using the plank test [36, 44] and 3 using sit-up exercises [31, 33, 45]. Andreasi et al. [39] failed to report a weight status comparison.

#### *Interventional Studies*

All included interventional studies showed improved lower limb performances [24, 19–21, 23–25, 28, 49]. Sgro et al. [20] described improved lower limb performance after 14 weeks of training compared with that after 8 and 16 weeks. Similarly, all interventional studies assessing upper limb performances found improvements by the end of their programme [24, 21–24, 49]. The two interventional studies assessing the effect of a training programme on abdominal strength failed to find any significant intervention effect [22, 24].

As this review tends to identify clinical and field test methods providing satisfactory results as compared with gold standard tests, field tests such as standing long jump or abdominal testing are widely used and are accurate ways to assess muscle strength in youth with obesity compared with laboratory-based methods.

## **Discussion**

The aim of this systematic review was to examine the effect of obesity on muscle fitness among children and adolescents. A total of 36 studies matched the inclusion criteria and was then analysed. While the majority of the included studies explored muscle fitness through

field tests, laboratory-based studies using ergometers provide an important objective approach to assessing muscle strength. This is of particular importance as the ability of children with obesity to produce strength during field testing does not solely reflect muscular capacity and fitness but also relies on other parameters of musculoskeletal health factors such as joint range of motion, flexibility, balance and coordination. Indeed, studies using field tests such as standing broad jumps or vertical jumps observed reduced lower limb performances in those with obesity compared to lean peers [31, 33, 37, 40–45, 50, 52], while almost all the laboratory-based trials underline a higher absolute strength production in those who are obese [28, 30, 32, 34, 47, 48, 53]. Laboratory-based studies, however, use uni- and bi-pedal leg press or leg extension testing on machines overcoming resistance ergometers that isolate single movements during which the participant's body mass is generally not involved (knee extensor contraction in supine position for instance). This underlines the need to consider body dimensions, when expressing muscle strength, especially in people with obesity. Effectively, once expressed considering body mass, laboratory-based strength results become significantly lower in those who are obese compared with their lean counterparts [28, 32, 34, 47, 48, 51]. This finding is in agreement with results obtained during field tests and suggests the good reliability of such field assessments compared with more objective laboratory-based methods.

Deforche et al. [33] and Fogelholm et al. [50] assessed both static and explosive strength in both lean adolescents and those with obesity. According to their studies, though participants with obesity perform better during static exercises compared to their lean counterparts, lean adolescents show better results during explosive tests [33, 50], which could be due to other parameters of musculoskeletal fitness. Interestingly, when expressed according to lean body mass (LBM), muscle torque becomes similar between youth who are lean and those who were obese [30, 32, 34, 47, 48, 53] and perhaps underlines a lower efficiency of the LBM to produce strength in those who are obese compared with lean subjects. However, LBM does not only represent skeletal muscle mass, and we found only 1 study that expressed muscle strength relative to muscle mass, measured via DXA, in children of both weight status [48]. In their work, Abdemoula and collaborators [48] also observed higher absolute strength values related to lower body mass and similar lower LBM-related strength in 12- to 14-year-old boys with obesity compared with lean ones. However, once muscle strength of the knee extensors was expressed relative to muscle mass only, those with obesity produced significantly more strength. Their results clearly illustrate the role of qualitative neuromuscular factors in the muscle strength production process in boys with obesity. Although research is scarce regarding the neuromuscular parameters involved in strength production in youth and particularly in youth who are obese, recent results suggested that youth with obesity have the ability to compensate for their larger body weight by increasing their level of voluntary activation during muscle contraction [54]. According to the authors, this reflects the ability of the adolescents' neuromuscular system plasticity to adapt itself to the body weight load, similar to what is observed after resistance training [54]. Interestingly the same team recently corroborated their hypothesis by showing that there are similar voluntary activation levels and that muscle strength is not different between adolescents who are obese or lean when non-weight-bearing skeletal muscles are examined (such as the Abductor pollicis) [54]. Although this represents a positive adaptation of the neuromuscular system to weight-bearing tasks (increased voluntary activation level in obesity), it has been shown that adolescents with obesity experience a higher energy cost of movement and greater muscular fatigability during exercise which could explain their limited engagement in physical activities [55]. If the neuromuscular system is able to adapt to weight-bearing activities, this clearly questions the impact of weight loss programmes on overall muscular fitness.



Further studies (field-based and laboratory-based) are needed to explore upper limb muscle strength and general muscular fitness as highlighted by the small number of studies found in this review and their conflicting results.

As described in this review, few studies examined the impact of weight loss on muscle function in obese children and adolescents ( $n = 9$ ), and all of them observed improved muscle fitness by the end of the respective interventions [19–21, 23, 24, 25, 28, 49]. Since all of those studies used field tests and incorporated movement skills and resistance sessions (combined or not with aerobic training), their results might reflect improvement in overall musculoskeletal fitness (coordination, balance, gait etc.), and not specifically muscle strength. Ongoing studies suggest the importance of incorporating resistance training in weight management interventions not only to maintain skeletal muscle mass but also to conserve the higher level of neuromuscular activation observed in youth with obesity [54].

Our review highlights the dearth of data examining muscular fitness specifically and musculoskeletal fitness more generally in youth with obesity ( $n = 36$ ). There is growing evidence concerning the importance of musculoskeletal fitness for overall health [12]. This is particularly true when considering the aforementioned interventional studies ( $n = 9$ ), and our review highlights a lack of detail around the methods and specific interventions utilised. Future studies should provide more detail regarding the protocols used in order to identify which type of physical activities have the best effects on muscular fitness in this population.

Although obesity is clearly described, the selected studies used national or international growth curves based on anthropometric measurements to diagnose obesity. It could be of particular interest to differentiate android and gynoid obesity forms when it comes to functional fitness and especially muscular fitness, since an individual's neuromuscular function might be differentially affected depending on the location of fat tissue [55]. This is particularly important since body fat location (android and gynoid) has been implicated in the metabolic profile of adolescents with obesity [56]. Indeed, paediatric obesity does not only describe anthropometric status but in many cases can be considered as a metabolic condition [57]. Further research is needed to explore the metabolic effects of impaired muscle function as data suggests that insulin resistance favours mitochondrial dysfunction within skeletal muscle which in turn increases muscle fatigability [58] and reduces post-effort muscle recovery [59]. Future research should also consider other important determinants of obesity including the length of exposure to the obese state and the underlying assumed cause (genetic, hormonal etc.). Similarly, most of the studies conducted so far miss to report indications regarding the participants' maturation status. This should be detailed in future research and used as a better comparison basis than age between lean and overweight/obese participants since obesity favours earlier maturation.

Importantly, our review reveals that routinely used field tests provide satisfactory results when analysing overall daily muscular fitness in children with obesity when compared to laboratory-based data. Physiotherapists and clinical practitioners are encouraged to systematically evaluate muscular fitness among their patients as part of an overall evaluation of musculoskeletal fitness while also assessing other parameters such as balance, coordination, flexibility, gait and posture.

## Conclusion

The results of this systematic review demonstrate strong evidence that children and adolescents with obesity have reduced muscular fitness compared with their lean counterparts and that qualitative physical-activity based weight management interventions should be a key feature of weight management interventions. While laboratory-based methods are

expensive and not easily accessible, batteries of field tests are available and provide satisfactory results in this population. Improving muscular fitness and overall musculoskeletal fitness in children with obesity is of crucial importance to favour their physical autonomy, promote engagement in daily activities and physical activity-based weight management programmes and subsequently improve their health-related quality of life.

### Authors' Contribution

TD, SRD, DW and GOM performed the researches and compiled the results. TD, SRD, DW, GOM and MLF analysed the results of the systematic review and wrote the paper. All co-authors were involved in the writing of the paper.

### Disclosure Statement

The authors have no conflict of interest to disclose.

### References

- 1 World Health Organisation: Obesity: preventing and managing the global epidemic. Report of WHO consultation. World Health Organ Tech Rep Ser 2000;894:1–253.
- 2 Spruijt-Metz D: Etiology, Treatment and prevention of obesity in childhood and adolescence: a decade in review. *J Res Adolesc* 2011;21:129–52.
- 3 Maffei C, Zaffanello M, Schutz Y: Relationship between physical inactivity and adiposity in prepubertal boys. *J Pediatr* 1997;131:288–292.
- 4 Lafortuna CL, Fumagalli E, Vangeli V, Sartorio A: Lower limb alactic anaerobic power output assessed with different techniques in morbid obesity. *J Endocrinol Invest* 2002;25:134–411.
- 5 Tomkinson GR, Leger LA, Olds TS, Cazorla G: Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20m shuttle run test in 11 countries. *Sports Med* 2003;33:285–300.
- 6 O'Malley G, Hussey J, Roche E: A pilot study to profile the lower limb musculoskeletal health in children with obesity. *Pediatr Phys Ther* 2012;24:292–298.
- 7 Llorente-Cantarero FJ, Perez-Navero JL, Benitez-Sillero Jde D, Munoz-Villanueva MC, Gil-Campos M: Evaluation of metabolic risk in prepubertal girls versus boys in relation to fitness and physical activity. *Gend Med* 2012;9:436–444.
- 8 Boreham C, Riddoch C: The physical activity, fitness and health of children. *J Sports Sci* 2001;19:915–929.
- 9 Dwyer T, Magnussen CG, Schmidt MD, Ukoumunne OC, Ponsonby AL, Raitakari OT, et al: Decline in physical fitness from childhood to adulthood associated with increased obesity and insulin resistance in adults. *Diabetes Care* 2009;32:683–87.
- 10 Bryant M, Ashton L, Nixon J, Jebb S, Wright J, Roberts K, et al: Framework of outcome measures recommended for use in the evaluation of childhood obesity treatment interventions: the CoOR framework. *Pediatr Obes* 2014;9:e116–131.
- 11 Armstrong N, Welsman JR (eds): *Young People and Physical Activity*. Oxford, Oxford University Press, 1997.
- 12 Cattuzzo MT, Dos Santos Henrique R, Re AH, de Oliveira IS, Melo BM, de Sousa Moura M, et al: Motor competence and health related physical fitness in youth: a systematic review. *J Sci Med Sport* 2016;19:123–129.
- 13 Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR: The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med* 2014;44:1209–1223.
- 14 Plowman SA: Top 10 research questions related to musculoskeletal physical fitness testing in children and adolescents. *Res Q Exerc Sport* 2014;85:174–187.
- 15 Page A, Cooper AR, Stamatakis E, Foster LJ, Crowne EC, Sabin M, et al: Physical activity patterns in nonobese and obese children assessed using minute-by-minute accelerometry. *Int J Obes (Lond)* 2005;29:1070–1076.
- 16 Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, et al: The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol* 2009;62:e1–34.
- 17 Moher D, Liberati A, Tetzlaff J, Altman DG: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg* 2010;8:336–341.
- 18 Higgins JP, Green SM, Collaboration C (eds): *Cochrane Handbook for Systematic Reviews of Interventions*. Wiley Online Library, 2008. <http://community.cochrane.org/handbook> (last accessed January 26, 2016).

- 19 McGuigan MR, Tataschiere M, Newton RU, Pettigrew S: Eight weeks of resistance training can significantly alter body composition in children who are overweight or obese. *J Strength Cond Res*. 2009;23:80–85.
- 20 Sgro M, McGuigan MR, Pettigrew S, Newton RU: The effect of duration of resistance training interventions in children who are overweight or obese. *J Strength Cond Res* 2009;23:1263–1270.
- 21 Dao HH, Frelut ML, Peres G, Bourgeois P, Navarro J: Effects of a multidisciplinary weight loss intervention on anaerobic and aerobic aptitudes in severely obese adolescents. *Int J Obes Relat Metab Disord* 2004;28:870–878.
- 22 Poeta LS, Duarte M, Giuliano I, Cazusa J: Interdisciplinary intervention on body composition and physical fitness tests in obese children. *Braz J Kinesiology Hum Perform* 2012;14:134–143.
- 23 Lau PWC, YU CW, Lee A, Sung RYT: The physiological and psychological effects of resistance training on Chinese obese adolescents. *J Exerc Sci Fit* 2004;2:115–120.
- 24 Pienaar AE, Du Toit D, Truter L: The effect of a multidisciplinary physical activity intervention on the body composition and physical fitness of obese children. *J Sports Med Phys Fit* 2013;53:415–427.
- 25 Karner-Rezek K, Knechtle B, Fenzl M, Schlegel C, Konrad M, Rosemann T: The effects of an 8-week multicomponent inpatient treatment program on body composition and anaerobic fitness in overweight and obese children and adolescents. *Int J Gen Med* 2013;6:159–166.
- 26 Lee S, Kim Y, White DA, Kuk JL, Arslanian S: Relationships between insulin sensitivity, skeletal muscle mass and muscle quality in obese adolescent boys. *Eur J Clin Nutr* 2012;66:1366–1368.
- 27 De Toia D, Klein D, Weber S, Wessely N, Koch B, Tokarski W, et al: Relationship between anthropometry and motor abilities at pre-school age. *Obes Facts* 2009;2:221–225.
- 28 Thivel D, Isacco L, Lazaar N, Aucouturier J, Ratel S, Dore E, et al: Effect of a 6-month school-based physical activity program on body composition and physical fitness in lean and obese schoolchildren. *Eur J Pediatr* 2011;170:1435–1443.
- 29 Pongprapai S, Mo-Suwan L, Leelasamran W: Physical fitness of obese school children in Hat Yai, southern Thailand. *Southeast Asian J Trop Med Public Health* 1994;25:354–360.
- 30 Lazzar S, Pozzo R, Rejc E, Antonutto G, Francescato MP: Maximal explosive muscle power in obese and non-obese prepubertal children. *Clin Physiol Funct Imaging* 2009;29:224–228.
- 31 Liao Y, Chang SH, Miyashita M, Stensel D, Chen JF, Wen LT, et al: Associations between health-related physical fitness and obesity in Taiwanese youth. *J Sports Sci* 2013;31:1797–1804.
- 32 Duche P, Ducher G, Lazzar S, Dore E, Tailhardat M, Bedu M: Peak power in obese and nonobese adolescents: effects of gender and braking force. *Med Sci Sports Exerc* 2002;34:2072–2078.
- 33 Deforche B, Lefevre J, De Bourdeaudhuij I, Hills AP, Duquet W, Bouckaert J: Physical fitness and physical activity in obese and nonobese Flemish youth. *Obes Res* 2003;11:434–441.
- 34 Aucouturier J, Lazaar N, Dore E, Meyer M, Ratel S, Duche P: Cycling peak power in obese and lean 6- to 8-year-old girls and boys. *Appl Physiol Nutr Metab* 2007;32:367–371.
- 35 Shang X, Liu A, Li Y, Hu X, Du L, Ma J, et al: The Association of weight status with physical fitness among Chinese children. *Int J Pediatr* 2010;2010:515414.
- 36 Ervin RB, Fryar CD, Wang CY, Miller IM, Ogden CL: Strength and body weight in US children and adolescents. *Pediatrics* 2014;134:e782–789.
- 37 Castro-Pinero J, Gonzalez-Montesinos JL, Mora J, Keating XD, Girela-Rejon MJ, Sjostrom M, 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;23:2295–2310.
- 38 Ceschia A, Giacomini S, Santarossa S, Rugo M, Salvadego D, Da Ponte A, et al: Deleterious effects of obesity on physical fitness in pre-pubertal children. *Eur J Sport Sci* 2015:1–8.
- 39 Andreasi V, Michelin E, Rinaldi AE, Burini RC: Physical fitness and associations with anthropometric measurements in 7- to 15-year-old school children. *J Pediatr (Rio J)* 10;86(6):497–502.
- 40 Dumith SC, Ramires VV, Souza MA, Moraes DS, Petry FG, Oliveira ES, et al: Overweight/obesity and physical fitness among children and adolescents. *J Phys Act Health* 2010;7:641–648.
- 41 Riddiford-Harland DL, Steele JR, Baur LA: Upper and lower limb functionality: are these compromised in obese children? *Int J Pediatr Obes* 2006;1:42–49.
- 42 Tokmakidis SP, Kasambalis A, Christodoulos AD: Fitness levels of Greek primary schoolchildren in relationship to overweight and obesity. *Eur J Pediatr* 2006;165:867–874.
- 43 Sacchetti R, Cecilian A, Garulli A, Masotti A, Poletti G, Beltrami P, et al: Physical fitness of primary school children in relation to overweight prevalence and physical activity habits. *J Sports Sci* 2012;30:633–640.
- 44 Dokic Z, Mededovic B: Relationship between overweight, obesity and the motor abilities of 9–12 year old school children. *Phys Culture* 2013;67:91–102.
- 45 Huang YC, Malina RM: Body mass index and individual physical fitness tests in Taiwanese youth aged 9–18 years. *Int J Pediatr Obes* 2010;5:404–411.
- 46 Ward DS, Trost SG, Felton G, Saunders R, Parsons MA, Dowda M, et al: Physical activity and physical fitness in African-American girls with and without obesity. *Obes Res* 1997;5:572–577.
- 47 Tsiros MD, Coates AM, Howe PR, Grimshaw PN, Walkley J, Shield A, et al: Knee extensor strength differences in obese and healthy-weight 10-to 13-year-olds. *Eur J Appl Physiol* 2013;113:1415–1422.
- 48 Abdelmoula A, Martin V, Bouchant A, Walrand S, Lavet C, Taillardat M, et al: Knee extension strength in obese and nonobese male adolescents. *Appl Physiol Nutr Metab* 2012;37:269–275.

- 49 Tsang TW, Kohn MR, Chow CM, Fiatarone Singh MA: Kung fu training improves physical fitness measures in overweight/obese adolescents: the ‘martial fitness’ study. *J Obes* 2010;2010. pii:672751.
- 50 Fogelholm M, Stigman S, Huisman T, Metsamuuronen J: Physical fitness in adolescents with normal weight and overweight. *Scand J Med Sci Sports* 2008;18:162–170.
- 51 Blimkie CJ, Sale DG, Bar-Or O: Voluntary strength, evoked twitch contractile properties and motor unit activation of knee extensors in obese and non-obese adolescent males. *Eur J Appl Physiol Occup Physiol* 1990;61:313–318.
- 52 Rauch R, Veilleux LN, Rauch F, Bock D, Welisch E, Filler G, et al: Muscle force and power in obese and overweight children. *J Musculoskelet Neuronal Interact* 2012;12:80–83.
- 53 Maffiuletti NA, Jubeau M, Agosti F, De Col A, Sartorio A: Quadriceps muscle function characteristics in severely obese and nonobese adolescents. *Eur J Appl Physiol* 2008;103:481–484.
- 54 Garcia-Vicencio S, Coudeyre E, Kluka V, Cardenoux C, Jegu AG, Fourot AV, et al: The bigger, the stronger? Insights from muscle architecture and nervous characteristics in obese adolescent girls. *Int J Obes (Lond)* 2015;doi:10.1038/ijo.2015.158.
- 55 Garcia-Vicencio S, Martin V, Kluka V, Cardenoux C, Jegu AG, Fourot AV, et al: Obesity-related differences in neuromuscular fatigue in adolescent girls. *Eur J Appl Physiol* 2015;115:2421–2432..
- 56 Aucouturier J, Meyer M, Thivel D, Taillardat M, Duche P: Effect of android to gynoid fat ratio on insulin resistance in obese youth. *Arch Pediatr Adolesc Med* 2009;163:826–831.
- 57 Thivel D, Malina RM, Isacco L, Aucouturier J, Meyer M, Duche P: Metabolic syndrome in obese children and adolescents: dichotomous or continuous? *Metab Syndr Relat Disord* 2009;7:549–555.
- 58 Slattery MJ, Bredella MA, Thakur H, Torriani M, Misra M: Insulin resistance and impaired mitochondrial function in obese adolescent girls. *Metab Syndr Relat Disord* 2014;12:56–61.
- 59 Fleischman A, Kron M, Systrom DM, Hrovat M, Grinspoon SK: Mitochondrial function and insulin resistance in overweight and normal-weight children. *J Clin Endocrinol Metab* 2009;94:4923–4930.