The Impact of Childhood Obesity on the Body Posture: a Systematic Review and Meta-analysis

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ABSTRACT:

Objective. It has been suggested that overweight/obesity (OW/OB) impairs the normal development of body posture in children and adolescents; however, to date, no study has systematically reviewed or quantified the effect of OW/OB on the development of postural alterations in children and adolescents. The purpose of this study was to systematically review the association between OW/OB and postural alterations in children and adolescents and to

quantify the evidence on whether children and adolescents with OW/OB have a higher risk of developing postural alterations than their peers of normal weight.

Methods. PubMed and Web of Science databases were systematically searched from inception to March 9, 2020. Studies investigating the association between OW/OB and postural alterations in children and adolescents were selected. Nonoriginal articles, participants with movement pattern diseases, and adolescents studied while pregnant were excluded. Two independent reviewers conducted the study selection and data extraction. Qualitative synthesis of evidence and random effect meta-analyses (risk ratio [RR]) were performed.

Results. Seventy-three studies (5 longitudinal and 68 cross-sectional) met the inclusion criteria involving 1,757,107 children and adolescents. There was consistent evidence supporting associations of OW/OB with rounded shoulder, lumbar hyperlordosis, genu valgum, and flatfoot. Our meta-analysis showed that children and adolescents with OW/OB had a significantly higher risk of lumbar hyperlordosis (RR = 1.41), genu valgum (RR = 5.92), flatfoot (RR = 1.49), and an overall altered posture (RR = 1.68) when compared with their peers of normal weight. The presence of genu valgum and flatfoot were the most robust results.

Conclusions. Based on these findings, OW/OB is associated with the presence of postural alterations in children and adolescents.

Impact. This is the first study that has systematically reviewed the effect of OW/OB on the development of postural alterations in children and adolescents.

Key words. Childhood obesity; Musculoskeletal diseases; Pain, Postural malalignments; Pes planus; Injury

INTRODUCTION

Childhood and adolescence overweight/obesity (OW/OB) is currently considered one of the most serious global public health challenges, affecting 340 million children and adolescents worldwide ¹. Apart from being a major risk factor for other serious diseases such as cardiovascular diseases, cancer and diabetes, OW/OB has been suggested to alter the structure and function of the young musculoskeletal system, although it has received relatively little attention within the literature ^{2,3}. Particularly, some authors have reported that OW/OB leads to postural alterations in children and adolescents (e.g., lumbar hyperlordosis, genu valgum or flatfoot), which are understood as non-optimal alignments of body segments ^{2,4,5}. These postural alterations involve mechanical stress on bones/joints and muscle over-activation, which over time triggers the onset of pain and more severe musculoskeletal disorders ^{2,6}. In fact, recent research revealed that children with OW/OB are at 26% higher risk of experiencing any kind of musculoskeletal disorders (i.e., pain, injuries and fractures) ⁷, as well as being more predisposed to develop osteoarthritis in adulthood ⁸.

During childhood and adolescence there are many external factors capable of influencing our posture, since one is then exposed to rapid physical and environmental changes ^{9,10}. The presence of OW/OB has been suggested to be an influential external factor, but further evidence is needed. Wearing et al. ² and Chan et al. ¹¹ described in their narrative reviews that childhood obesity may influence the optimal lower limb musculoskeletal structure. Stolzman et al. ⁵ showed that children with OW/OB have higher prevalence of presenting with flatfoot than children with normal weight. However, to date, neither has any study systematically reviewed the literature investigating the relationship between OW/OB and postural alterations in the entire musculoskeletal system in children and adolescents, nor have any results been synthesized with a

standardized protocol (i.e., meta-analysis and/or qualitative synthesis). This can help us better understand the impact of OW/OB on the musculoskeletal system of children and adolescents and, in turn, its implications on the onset and progression of musculoskeletal disorders.

The aims of the present systematic review and meta-analysis were 1) to examine the association between OW/OB indicators (e.g., body mass index [BMI] or fat mass index) and postural alterations in children and adolescents, and 2) to synthesize evidence of whether children and adolescents with OW/OB are at a higher risk of experiencing postural alterations in comparison with children with normal weight.

METHODS

This systematic review was guided by the Meta-analysis Of Observational Studies in Epidemiology (MOOSE) ¹² and the review protocol was registered in the International Prospective Register of Systematic Reviews (<https://www.crd.york.ac.uk/prospero/>) with reference number: CRD42019129093.

Data sources and search strategy

PubMed and Web of Science were searched from inception to March 9, 2020. Two researchers with expertise in the topic defined the search strategy (J-V and P-MG), which is available in Supplementary Table S1. Reference lists of included studies were reviewed to find other potentially eligible studies.

Study selection

Two researchers (P.M.G. and D.M.A.) independently performed the study selection process and any discrepancy was resolved through discussions and consensus. Studies were included if the following inclusion criteria were satisfied: (1) designs were prospective

longitudinal or cross-sectional without any special requirement of sample size nor writing language; (2) participants were children or young (up to 21 years old) assessed by any fatness indicator (e.g., BMI); and (3) outcomes were postural alterations. Studies were excluded if they: (1) were not original articles (i.e., meeting abstracts, editorials, letters to editor, or reviews); (2) included participants with chronic movement pattern diseases (e.g., cerebral palsy) or (3) included adolescents in pregnancy stage, since this is known to alter their normal body posture. The systematic review software “Covidence” (www.covidence.org; Veritas Health Innovation) was used in the study selection process.

Data extraction

The following information was extracted from the included studies: 1) author’s name and year of publication, 2) country of the study, 3) total sample size and characteristics of the participants, 4) study design, 5) body composition indicators and assessment instruments, 6) body posture measures and assessment instrument and 7) main findings. The extraction of the data was done by two independent researchers (P.M.G. and D.M.A.) and any disagreements were discussed until consensus was reached.

Risk of Bias

The Joanna Briggs Institute Critical Appraisal Tool for Systematic Reviews was used to evaluate the quality of both longitudinal and cross-sectional studies ^{6,13}. This tool provides ten quality criteria items for longitudinal studies and eight for cross-sectional studies, each of which have three possible answers: “yes” (criterion met), “no” (criterion not met) and “not applicable” (Supplementary Table S2). The percentage of positively scored criteria with respect to the total number of applicable criteria was calculated for each study as an indicator of quality. A study was considered as “Low Risk of Bias” when the positively scored percentage was at least

75%. Two independent researchers (P.M.G. and D.M.A.) accomplished this process and disagreements were discussed to reach consensus.

Qualitative evidence synthesis

All results, from both longitudinal and cross-sectional studies, were synthesized through the method firstly used by Sallis et al.¹⁴ and more recently by Rodriguez-Ayllon et al.¹⁵. This method rates the results based on the following criteria: 1) If 0% to 33% of the studies reported a statistically significant association of a postural alteration with BMI and/or obesity degree, the result was classified as no association (Ø); 2) if 34% to 59% of studies reported a significant association, or if fewer than four studies reported on this postural alteration, the result was classified as being inconsistent/uncertain (?); and 3) if $\geq 60\%$ of the studies found a statistically significant association, the result was classified as positive (+) or negative (-), depending on the direction of the association. In those studies that the association was tested separately in girls and boys or in children and adolescents, we specified it as '♀' or '♂' and 'C' or 'A', respectively. Furthermore, these separate associations were quantified with a 0.5 score instead of 1, as previous authors did¹⁵. Sensitivity analyses were performed by only including studies with low risk of bias.

Meta-Analysis

Added to the qualitative evidence synthesis, quantitative meta-analysis was undertaken. Since the majority of the included studies compared the prevalence of having postural alterations between children with OW/OB and children with normal weight, we decided to perform a meta-analysis of dichotomous outcomes. The random effect models of the inverse variance method was used to calculate the pooled risk ratio (RR) and the corresponding 95% CI for different postural alterations in children with OW/OB and children with normal weight. Heterogeneity

was assessed with the Higgins I^2 statistic and P values, being classified as not important (0%-40%), moderate (30%-50%), substantial (50%-75%) or considerable (75%-100%).¹⁶

Sensitivity analyses were performed by removing studies one at time and testing whether the overall effect size (i.e., z score) was significantly modified in magnitude or direction. This analysis provided information about the robustness of the synthesis of the evidence provided. As we did in the qualitative evidence synthesis, sensitivity analyses were performed only considering studies with a low risk of bias. A funnel plot and the Egger regression asymmetry test (a level of <0.10) were used to assess publication bias¹⁷. Analyses were performed using the Review Manager Version 5.3 (The Nordic Cochrane Center, The Cochrane Collaboration, 2014, Copenhagen, Denmark).

Role of the Funding Sources

None of the funders had any role in the design and conduct of the present work.

RESULTS

Study selection

The PRISMA flow diagram (Fig. 1) shows that among the 1116 nonduplicated articles, 937 were excluded after an abstract review, and 87 after a full-text review, having thus 73 articles that met our inclusion criteria.

Sample characteristics

Supplementary Table S3 summarizes the characteristics of the 73 included studies. Of these studies, five used a longitudinal design and the 68 remaining a cross-sectional design. The whole sample size of the included studies was 1,757,107 children and adolescents with ages ranging from 0 to 21 years old. All studies used BMI as OW/OB indicator, whereas three studies additionally reported fat mass composition^{18–20}, two reported muscle mass composition^{18,20}, two reported waist circumference^{21,22} and one reported height-waist circumference²³. BMI was always used to measure the obesity degree, and a wide range of cut-off points were identified: 22 studies used the Extended International (IOTF) cut-offs^{24–44}, seven the 90th and 97th percentiles (OW and OB respectively)^{45–51}, seven cut-off points from their countries (Czech Republic, Mexico, Poland, Taiwan and USA)^{18,52–57}, six the World Health Organization cut-offs^{58–63}, six the Centers for Disease Control and Prevention cut-offs^{64–69}, one the National Institute of Health cut-offs⁷⁰, and one did not report it⁷¹. Regarding postural alterations, four articles studied forward head^{72–75}, five rounded shoulder^{18,19,72,73,76}, 12 thoracic hyperkyphosis^{10,18,23,34,59,70,72,74,75,77–79}, 14 lumbar hyperlordosis^{18,20,23,34,48,59,72,74,75,77–81}, 11 scoliosis^{28,48,55,56,65,67,70,72,76,78,82}, six flat spine^{20,72,77,79–81}, six forward sway posture^{74,75,77,79–81}, 15 genu valgum^{22,25,31,42,45,46,48,57,58,64,66–68,72,83}, three genu recurvatum^{22,48,67} and 40 flatfoot^{19,21,24–27,29–32,33,35–43,44,47,49–54,60,62,63,69,71,72,78,84–88}. Table 1 provides a definition of each postural alteration as well as the assessment protocol by which these were diagnosed. High risk of bias was detected in 16 cross-sectional (N total = 68, 24%) and three longitudinal studies (N total = 5, 60%) (Supplementary Table S4).

Qualitative evidence synthesis

The associations between OW/OB and the ten postural alterations were investigated in the seventy-three included studies (Tab. 2). There was consistent evidence supporting associations of

OW/OB with the presence of rounded shoulders (3.5/5 studies; 70%), lumbar hyperlordosis (9.5/14 studies; 67.9%), genu valgum (14/15 studies; 93.3%) and flatfoot (31.5/40 studies; 79.0%). There was consistent evidence supporting the lack of an association of OW/OB with flat spine (4/6 studies; 66.7%), with forward head (1/4 studies; 25.0%), or with scoliosis (2.5/11 studies; 22.7%). There was unclear evidence supporting associations of OW/OB with the presence of forward sway posture (3.5/6 studies; 58.3%) and thoracic hyperkyphosis (7/12 studies; 58.3%), and insufficient evidence to determine the association of OW/OB with genu recurvatum (3/3 studies; 100%). Sensitivity analyses only including studies with low risk of bias (Suppl. Tab. S5) demonstrated that OW/OB was consistently associated with lumbar hyperlordosis (7.5/10 studies; 75.0%), genu valgum (12.5/14 studies; 89.3%) and flatfoot (25.5/31 studies; 82.3%).

Meta-analysis

Given the considerable heterogeneity between studies in all subgroups ($I^2 > 85\%$; $P < 0.001$), the random-effects model continued to be applied. Figure 2 presents the meta-analysis of the association between OW/OB during childhood and adolescence and the presence of postural alterations. Children and adolescents with OW/OB had higher risk of presenting with lumbar hyperlordosis ($RR = 1.41$; 95% CI = 1.03–1.92; $P < .030$), genu valgum ($RR = 5.92$; 95% CI = 4.38–8.00; $P < .001$), flatfoot ($RR = 1.49$; 95% CI = 1.34–1.65; $P < .001$), and overall altered posture ($RR = 1.68$; 95% CI = 1.35–2.08; $P < .001$) compared with their peers of normal weight. Children and adolescents with OW/OB had higher risk of presenting with thoracic hyperkyphosis ($RR = 1.35$; 95% CI = 0.74–2.45; $P = .330$), although not statistically significant, while they had no higher risk of presenting with scoliosis ($RR = 0.82$; 95% CI = 0.61–1.09; $P = .170$) in comparison with normal weight. A schematic summary of postural alterations found in

children and young with OW/OB from both analyses (i.e., qualitative evidence synthesis and meta-analysis) is presented in Figure 3. Sensitivity analyses showed that only overall effect sizes of genu valgum and flatfoot were not significantly modified when removing individual studies (Suppl. Tab. S6), while results remained similar by including only studies with low risk of bias (Suppl. Fig. S1). Finally, evidence of publication bias was only found by funnel plot asymmetry and the Egger test for scoliosis subgroup ($P = .065$) (Suppl. Fig. S2).

DISCUSSION

The main findings of this study were 1) higher OW/OB degree, determined by BMI, was associated with the presence of four postural alterations, namely rounded shoulders, lumbar hyperlordosis, genu valgum and flatfoot; 2) children and adolescents with OW/OB had 1.4 times the risk of presenting with lumbar hyperlordosis, 5.9 times the risk of presenting with genu valgum, 1.5 times the risk of presenting with flatfoot and 1.7 times the risk of presenting with any kind of postural alteration compared to those with normal weight, and 3) the presence of genu valgum and flatfoot were the most robust results since were observed in both qualitative and quantitative synthesis and remained unchanged after sensitivity analyses.

The musculoskeletal system is in continuous development during childhood and there are some developmental stages when it is especially exposed to external factors, such as OW/OB. For instance, from the newborn to the toddler stage (i.e., 0-4 years old), children experience important changes by reaching physiological alignments in the spinopelvic structure and lower limbs, which agrees with the acquisition of upright posture and walking abilities^{64,89}. In this review, those studies that included newborn children until the age of four did not find associations between OW/OB and postural alterations in the spinopelvic structure or lower limbs, whereas they did in older children^{31,64,72,81}. Regarding feet, the only two studies analyzing

age groups in the first years of life did not find associations between OW/OB and flatfoot at 3 to 5 years of age, whereas they started to see differences at 5 to 7 years of age^{31,72}. These facts evidence that postural alteration could be originating during this first stage of childhood.

Puberty is also a critical period for the development of the musculoskeletal system⁷². It is also when morphological differences between genders become more evident, especially in the anatomy of the spinopelvic structure and lower limbs^{90,91}. At puberty, girls tend to demonstrate more pelvic anteversion (associated with lumbar hyperlordosis) and genu valgum^{68,92}, whereas boys demonstrate more thoracic hyperkyphosis⁹². In feet anatomy some authors support a higher prevalence of flatfoot in boys due to a later plantar arch maturation in comparison with girls^{27,49}. The detrimental effect of OW/OB in the musculoskeletal system could be manifesting differently in girls and boys, probably aggravating postural dimorphisms that naturally occur in both genders, but further research is still needed to confirm this general belief.

The majority of studies suggest that mechanical constraints due to the excess of body mass could be driving the development of postural alterations in childhood and adolescence^{10,20}. In the spinopelvic structure, the excess of body mass could be influencing the mechanical stability of the spinal column, leading to compensations such as lumbar hyperlordosis^{20,77}. Araujo et al.²⁰ argued that fat mass accumulation might have a greater implication in the spinal imbalance, which leads to an increase in muscle tone of stabilizer muscles to counteract it²⁰. Excessive body mass has also suggested to induce a collapse of the lower limb into a valgus position. In the first years of life, children experience a physiological transitioning from varus towards valgus alignments as a mechanical adaptation to carry their increasingly heavy bodies⁹³. In children with OW/OB this transition could be exacerbated towards a more pronounced valgus position as an adaptation to support their higher body mass⁶⁴. With regards to feet, some authors suggest

that the medial longitudinal arch experiences a better development when the foot does not support an excessive body mass, which is directly linked to the incidence of flatfoot ³⁶. The continued bearing of excessive body mass has been suggested to lead to structural modifications in the navicular and cuneiform bones, which places muscles and ligaments in an excess of strain to hold a physiological height of the medial longitudinal arch that finally tends to collapse ^{38,61}. Others have suggested that flatfoot in children with OW/OB is caused by a thicker plantar fat pad, but this hypothesis was discarded after verifying that no differences exist in the plantar fat pad between children with OW/OB and children with normal weight ^{36,37}.

The qualitative evidence synthesis of this review clearly demonstrated no associations of OW/OB with the presence of a forward head posture or scoliosis. Strength of neck stabilizer muscles and cervical mobility are factors associated with an optimal head position but ⁷³, based on our results, OW/OB seems not to be an additional factor in the presence of a forward head posture. Some studies reported that not high but low BMI was associated with the presence of scoliosis ^{28,65,70}. It is well known that low body mass during childhood negatively affects bone health (e.g., osteopenia) and poor bone health has been linked to the development of scoliosis and its progression ⁷⁰. The lack of association between OW/OB and flat spine is in line with the presence of lumbar hyperlordosis in this population. Lastly, further evidence is still needed investigating those postural alterations with inconsistent and insufficient results (i.e, hyperkyphosis, forward sway and genu recurvatum).

Children and adolescents with OW/OB spend more time in sedentary behaviors and less practicing physical activity, lifestyle factors that might be additionally affecting their body posture. O'Sullivan et al. ¹⁰ found in adolescents that increased television use was associated with a thoracic hyperkyphosis posture during sitting and the presence of low back pain. A higher

level of physical activity in childhood and adolescence was related to a more aligned body posture, whereas lower physical activity levels were associated with increased pressure under the midfoot, which is a typical sign of flatfoot^{18,94}. Based on this evidence, children and adolescents with OW/OB spending less time in sedentary behaviors and undertaking more physical activity could help prevent the onset of these postural alterations. In fact, previous exercise-based intervention studies in this population have already demonstrated improvements in the spine, lower limbs, or foot structure and function^{95–97}, but the available evidence is still scarce.

Childhood obesity has already demonstrated to be linked with a higher prevalence pain and injuries,⁷ as well as with the development of more severe of musculoskeletal disorders later in life such as osteoarthritis.⁸ Findings from this review will help to gain a better understanding of the pathogenesis of these disorders by pointing postural alterations as a potential development factor. Among the included studies, five analyzed the relationship between postural alterations and musculoskeletal pain, with four of them finding significant associations^{10,55,67,70,79}. For instance, a non-neutral position of the spine (i.e., hyperkyphosis and hyperlordosis) and an overall poor posture were associated with a higher incidence of pain in the cervical spine and low back^{10,55,70,79}. The lumbar hyperlordotic posture observed in children and adolescents with OW/OB might have severe consequences across the lifespan, since it has been associated with the presence of low back pain and more severe spine pathologies in adulthood^{81,98}. In the lower limbs, a non-physiological alignment leads to abnormal load mechanics, which causes damage to the articular cartilages of the hip and knee joints over time⁶⁴. The genu valgum posture observed in this population was already reported during walking in a recent systematic review⁶, which evidences that these biomechanical alterations occur both in static and dynamic situations. The only previous systematic review investigating flatfoot in pediatric obesity did not find any study

addressing the possible short-term complications in the development of foot pain ⁵. However, when flatfoot persists into adulthood it is known to be the cause of foot pain and more severe complications ³⁰.

Limitations

Several limitations in this systematic review should be addressed. First, the use of only two databases (PubMed and Web of Science) may have left out articles related to this topic. Second, our findings are mainly based on cross-sectional studies (68/73 studies) and it does not allow to establish firm causality conclusions. Third, we found a wide variety of assessment protocols to identify postural alterations as well as different cut-off points to determine obesity degrees, which could be behind the substantial heterogeneity found in the meta-analysis. Thus, results should be treated with caution when extrapolated to the general population and future longitudinal studies with greater homogeneity are needed. Fourth, only 26 out of the 73 included studies that accounted for potential confounders such as age, maturational stage or gender in their statistical analysis. Fifth, there is no current literature supporting that the presence of postural alterations due to OW/OB predicts the development of musculoskeletal disorders in later adulthood and, therefore, all statements around that are still based on observational studies and assumptions.

CONCLUSION

Based on the qualitative evidence synthesis, OW/OB is associated with the presence of rounded shoulders, lumbar hyperlordosis, genu valgum and flatfoot in childhood. Based on the meta-analysis, children and adolescents with OW/OB have 1.4 times the risk of presenting with lumbar hyperlordosis, 5.9 times the risk of presenting with genu valgum, 1.5 times the risk of presenting with flatfoot and 1.7 times the risk of presenting with any kind of postural alteration

compared with their peers of normal weight. It is safe to say that ongoing and future efforts to prevent and reverse these postural alterations associated with OW/OB in childhood and adolescence are justified.

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AUTHOR CONTRIBUTIONS

P. Molina-Garcia conceptualized and designed the work, led all the phases of the systematic review (Prospero registration, study selection, data extraction, risk of bias and data synthesis) and drafted the initial manuscript.

D. Miranda-Aparicio participated in all phases of the systematic review, with the exception of data synthesis, and reviewed the manuscript for important intellectual content.

E. Ubago-Guisado and C. Alvarez-Bueno coordinated the data synthesis, especially the meta-analysis, and revised the manuscript.

J. Vanrenterghem and F.B. Ortega participated in the work design, supervised the whole process, helped with the drafting, and revised the manuscript providing critical content.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

ACKNOWLEDGMENTS

The authors thank Ms. Ana Yara Postigo-Fuentes for the English revision.

FUNDING

This study is supported by the Ministerio de Economía y Competitividad (MINECO) (Grant Numbers: DEP2013-47540 and BES-2014-068829), the European Regional Development Fund (Grant Numbers: DEP2016-79512-R and RD16/0022), the Horizon 2020 Framework Programme (Grant Number: 667302) and the Secretaría de Estado de Investigación, Desarrollo e Innovación: Universidad de Granada. The funders provide economic support to some of the researchers as well as the PROFITH research group.

SYSTEMATIC REVIEW REGISTRATION

This review protocol is registered in the International Prospective Register of Systematic Reviews at <https://www.crd.york.ac.uk/prospero/> (no. CRD42019129093).

DISCLOSURES

All authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

SUPPLEMENTARY FILES

Figure S1. Sensitivity analysis of the meta-analysis that only includes studies with low risk of bias. Contributing studies are sorted in chronological order. The green symbol corresponds to “Low Risk” studies and the red symbol corresponds to “High Risk” studies.

Figure S2. Funnel plot and Egger tests to assess the publication bias.

Table S1. Search terms used in PubMed and Web of Science databases.

Table S2. Criteria for the methodological quality assessment of cross-sectional and longitudinal articles, and the percentage of studies meeting these criteria.

Table S3. Summary of included studies.

Table S4. Quality assessment of cross-sectional and longitudinal articles.

Table S5. Summary table of the associations observed between overweight/obesity and postural alterations only including studies with low risk of bias.

Table S6. Sensitivity analysis of the robustness of the meta-analysis.

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TABLES

Table 1. Definition and assessment method of the postural alterations included^a

Postural alterations	Definition	Measures
Forward head	Forward inclination of the head with regards to the thorax, normally accompanied by a cervical spine hyperextension.	2-D photogrammetry ⁷³⁻⁷⁵ , musculoskeletal examination ⁷²
Rounded shoulders	Forward inclination of the shoulders with regards to the thorax, associated with a protracted position of the scapula and an internal rotation of the glenohumeral joint.	2-D photogrammetry ^{18,19,73} , musculoskeletal examination ^{72,76}
Thoracic hyperkyphosis	Increased backward curve in the upper back, characterized by a thoracic flexion.	2-D photogrammetry ^{10,18,23,59,74,75,77-79} , musculoskeletal examination ^{70,72}
Lumbar hyperlordosis	Increased lumbar lordosis curve characterized by a hyperextended lumbar spine and an anterior tilt of the pelvis.	2-D photogrammetry ^{18,20,81,23,59,74,75,77-80} , musculoskeletal examination ^{48,72}
Scoliosis	Lateral curve of the spine toward one side or both sides.	X-ray ^{65,82} , 2-D photogrammetry ^{28,70,78} , musculoskeletal examination ^{48,55,56,67,72,76}
Flat spine	Straight position of the spine characterized by the lack of physiological curvatures in thoracic and lumbar spine and a posterior tilt position of the pelvis.	2-D photogrammetry ^{20,77,79-81} , musculoskeletal examination ⁷²
Sway-back posture	Backwards inclination of shoulders and chest while forward inclination of the pelvis, all with respect to feet position.	2-D photogrammetry ^{74,75,77,79-81}
Genu valgum	Knees are close each other whereas feet are apart, characterized by hip adduction with internal rotation and knee abduction.	DEXA images ^{57,64} , 3-D photogrammetry ⁴⁶ , Goniometry ^{22,31,45,58,68,83,99} , musculoskeletal examination ^{48,66,67,72}
Genu recurvatum	Hyperextension of the knee accompanied by ankle plantarflexion.	Goniometry ²² , musculoskeletal examination ^{48,67}
Flatfoot	Drop of medial longitudinal arch of foot which is normally accompanied by a foot pronation pattern (i.e., ankle dorsiflexion and abduction and talonavicular eversion)	MRI ⁸⁶ , X-rays ²⁴ , 3-D scan ^{27,35,36} , ultrasound ^{37,39,40} , footprint ^{37,38,40,44,51,61} , plantar pressure ^{21,26,78,84,85,29,49,50,53,63,69,71,72} , musculoskeletal examination

^a 2-D = 2-dimensional; 3-D = 3-dimensional; DEXA= dual energy X-ray absorptiometry; MRI = magnetic resonance imaging.

Table 2. Summary table of the associations observed between overweight/obesity and postural alterations^a

Studies	N	Population	Upper body postural alterations					Lower body postural alterations				
			Head protraction	Rounded shoulders	Thoracic hyperkyphosis	Lumbar Hyperlordosis	Scoliosis	Flat spine	Forward sway posture	Genu valgum	Genu recurvatum	Flatfoot
Longitudinal												
Araujo et al, 2017 ⁸¹	2130	Child				+♂/Ø♀			Ø			
Chen et al, 2013 ⁵⁴	580	Children										+♂/Ø♀
Jankowicz-Szymanska et al, 2015 ³⁰	207	Child										+
Martinez-Nova et al, 2018 ⁸⁴	1032	Child										Ø
Smith et al, 2011 ⁷⁷	1373	Child & Adol			+	+		Ø	+			
Cross-sectional												
Alfahed et al, 2019 ⁹⁹	469	Child & Adol								+		
Araujo et al, 2017 ⁸⁰	2398	Child				+		-	+♀/Ø♂			
Araujo et al, 2017 ²⁰	2398	Child				+		-				
Araujo et al, 2019 ⁷⁵	2117	Child	Ø		+	+			+			
Arruda et al, 2009 ⁷⁸	100	Child			+	+	+					+
Asencio et al, 2019 ²⁴	104	Child										+
Bafor et al, 2012 ⁸³	471	Child								-		
Bonet et al, 2003 ⁴⁵	64	Child								+		
Bout-Tabaku et al, 2015 ⁶⁴	320	Child & Adol								-C/+A		
Briggs et al, 2017 ⁴⁶	40	Child & Adol								+		
Brito-Hernández et al, 2018 ²³	80	Child			Ø	Ø						
Brzeziński et al, 2019 ²⁵	6992	Child								+		+
Carvalho et al, 2017 ²⁶	1394	Child										-
Cetin et al, 2010 ⁴⁷	625	Child										+
Chang et al, 2009 ⁵²	2083	Child										+
Chen et al, 2009 ²⁷	1024	Child										+
Chen et al, 2011 ⁵³	1598	Child										+
Ciaccia et al, 2017 ⁵⁸	1050	Child								+		
Cimolin et al, 2016 ⁵¹	18	Adol										+

de Sa Pinto et al, 2006 ⁴⁸	96	Child & Adol			Ø	Ø		+	+	
Dolphens et al, 2018 ²⁸	1196	Child				-♀/♂Ø				-
Evans, 2011 ²¹	140	Child								-
Evans et al, 2015 ²⁹	728	Child & Adol								Ø
Gijon-Nogueron et al, 2017 ⁴⁹	1798	Child								-
Gijon-Nogueron et al, 2019 ⁵⁰	3217	Child & Adol								Ø
Hawke et al, 2016 ⁸⁵	30	Child & Adol								Ø
Hershkovich et al, 2014 ⁶⁵	82979	Adol								
Hershkovich et al, 2019 ⁶⁶	82138	Adol						+		
Jankowicz-Szymanska et al, 2016 ³¹	1364	Child						+		+
Jankowicz-Szymanska et al, 2017 ³²	400	Child								+
Jankowicz-Szymanska et al, 2018 ³³	96	Child								+
Jankowicz-Szymanska et al, 2020 ³⁴	910	Child	Ø		+	Ø				
Jannini et al, 2011 ⁶⁷	200	Adol				Ø		+	+	
Jiménez-Ormeño et al, 2013 ³⁵	1045	Child								+
Kothari et al, 2016 ⁸⁶	84	Child & Adol								Ø
Kratěnová et al, 2007 ⁵⁵	3520	Child & Adol						-		
Kuligowski et al, 2015 ⁵⁹	94	Child	Ø		Ø					
Lonner et al, 2015 ⁷⁰	1523	Child & Adol	+			Ø				
Lopez-Fuenzalida et al, 2016 ⁶⁰	388	Child								+
Maciańczyk-Paprocka et al, 2017 ⁷²	2732	Child & Adol	Ø	+C/ØA	-	Ø	Ø	Ø	+	+
Mauch et al, 2008 ³⁶	2887	Children								+
Merder-Coskun et al, 2017 ⁷¹	318	Children								+
Mickle et al, 2006 ³⁷	38	Children								+
Mickle et al, 2006 ³⁸	34	Children								+

Nery et al, 2010 ⁷⁶	1340	Child		+				Ø				
O'Malley et al, 2012 ²²	17	Child							+		+	
O'Sullivan et al, 2011 ¹⁰	1596	Child				+						
Ormos et al, 2016 ⁷³	428	Child	+		Ø							
Park et al, 2013 ⁸²	128	Adol						Ø				
Pfeiffer et al, 2006 ⁸⁷	835	Child										+
Pourghasem et al, 2016 ⁶¹	1158	Child & Adol										+
Riddiford-Harland et al, 2000 ⁶²	431	Children										+
Riddiford-Harland et al, 2011 ³⁹	150	Children										+
Riddiford-Harland et al, 2011 ⁴⁰	252	Children										+
Rusek et al, 2018 ¹⁹	464	Child & Adol		+								
Sadeghi-Demneh et al, 2016 ⁴¹	667	Children										+
Seah et al, 2011 ⁷⁴	121	Adol	Ø		Ø	+		Ø				
Senadheera et al, 2016 ⁶³	722	Child										+
Shapouri et al, 2019 ⁴²	1450	Child							+			+
Shohat et al, 2018 ⁶⁸	47588	Adol							+			
Smith et al, 2008 ⁷⁹	766	Child & Adol			+	+	-	+				
Taylor et al, 2006 ⁵⁷	355	Adol							+			
Tenenbaum et al, 2013 ⁶⁹	82596	Adol										+
Villarroya et al, 2008 ⁴³	245	Child & Adol										+
Villarroya et al, 2009 ⁴⁴	119	Child & Adol										+
Wozniacka et al, 2013 ⁸⁸	1115	Children										+
Wyszyńska et al, 2016 ¹⁸	120	Child & Adol		+		+	+					
Zurita et al, 2014 ⁵⁶	295	Child						Ø				
Summary												
+			1.0	3.5	7.0	9.5	1.0	0.0	3.5	14.0	3.0	31.5
-			0.0	0.0	1.0	0.0	2.5	4.0	0.0	1.0	0.0	4.0
Ø			3	1.5	4.0	4.5	8.5	2.0	2.5	0	0	4.5
Consistency (%)			25.00	70.00	58.33	67.86	20.83	66.67	58.33	93.33	100.00	78.75
Final score			Ø	+	?	+	Ø	-	?	+	?	+

^aAll included associations used body mass index (BMI) as overweight/obesity indicator. Associations between overweight/obesity and postural alterations were considered in the following cases: 1) continuous BMI associated with continuous posture indicator (e.g., correlation or linear regression), 2) BMI categories. Consistency was calculated by summing the number of positive or negative associations, the most frequently reported direction, dividing it by the total number of studies in this postural alteration, and then multiplying the results by 100. If consistency was 0%–33%, the result was classified as no association (Ø). If consistency was 34%–59%, or if fewer than 4 studies reported on the outcome, the result was classified as being inconsistent/uncertain (?). If consistency was ≥60%, the result was classified as positive (+) or negative (–), depending on the direction of the association.

Child = children; Adol = adolescents. Ø, +, or - indicates no association, positive or negative association, respectively, in boys (♂) or girls (♀); -/+ indicates negative association in children but positive association in adolescents; +/- Ø: indicates positive association in children but no association in adolescents.

FIGURE LEGENDS

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of study selection, inclusion and exclusion of studies.

Figure 2. Summary risk ratio (RR) of the relationship of having overweight/obesity during childhood and adolescence and to present postural alterations. Contributing studies are sorted in chronological order.

Figure 3. Schematic summary of the postural alterations associated with overweight/obesity in children and adolescents. Postural alterations presented were those demonstrating a consistent association (ie, >60%) with OW/OB in the qualitative evidence synthesis, those within the dotted box also demonstrated a relationship in the meta-analysis and those within the solid box were robust after sensitivity analyses. Consistency percentage from the qualitative evidence synthesis and relative risk from the meta-analysis are reported.