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Review

Biomechanical comparison of sagittal vertebral column bend change induced by backpacks in school-aged children and adolescents: Systematic review and network meta-analysis

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Abstract: Background: Studies have investigated the effects of backpacks and their loadings on the physiological spinal curvature changes in school-aged children and adolescents across different anatomical planes of motion. However, the dose-response relationship between varying backpack weights and changes in spinal physiological curvature remains unclear due to the uniformity of study protocols. **Objective:** The purpose of this systematic review is to explore the sagittal vertebral column bend change induced by backpacks in school-aged children and adolescents. **Methods:** Three relevant authoritative databases (PubMed, Scopus, and Web of Science) were searched. Indicators of vertebral column bend in the sagittal plane were selected as the outcomes. In the data organization phase, the extracted data were standardized and pooled together by the Aggregate Data Drug Information System. The Cochrane Risk of Bias Assessment Tool and the website of Confidence in Network Meta-Analysis were used to evaluate the risk of bias and confidence ratings of results. **Results:** 4 trials were included within 244 potential studies. The results indicated a potential dose-effect relationship between backpack weight and sagittal vertebral column bend change. The findings suggested a possible dose-response relationship between backpack weight and sagittal vertebral column bend change, as evidenced by a sequential reduction in the likelihood of causing the most negative effect on sagittal vertebral column bend in 4 backpack scenarios: without backpack, <10%, 10–20%, and >20% of body weight, with probabilities of 0.61, 0.25, 0.13, and 0.01, respectively. The results also indicated that there were no significant differences in the effects on the sagittal vertebral column bend between the four backpack scenarios, in pairwise comparisons. Additionally, the results from the risk of bias assessment revealed that this review suffers from a lack of inclusion of high-quality studies. Moreover, the confidence rating indicated that both direct and indirect comparisons in the network meta-analysis were rated as "Very Low" in confidence rating induced by CINeMA. **Conclusion:** This review suggests a potential dose-effect relationship between backpack weight and sagittal vertebral column bend, with no significant differences across each head-to-head comparison.

Keywords: backpack; vertebral; spine; posture; systematic review; network meta-analysis

1. Introduction

The incidence of posture-related issues among these individuals has become increasingly acknowledged in recent years [1,2]. Common posture problems include scoliosis, forward head posture, leg misalignment, and flat feet [3]. The spine is a focal area for numerous posture problems [4,5]. Various studies indicate that backpacks significantly affect posture issues, particularly those involving the spine. Studies have shown that the weight of a backpack influences lumbar intervertebral disc deformation, and there exists a positive relationship between the load and vertebral column curvature [6]. Additionally, the growing usage of school backpacks has brought the matter of their weight into greater focus [7]. When different weights of backpacks are applied to children’s lumbar vertebrae, which are the largest weight-bearing cones [8]. In the school-age phase, children encounter multiple stages of postural development along with considerable growth changes [9]. During these school years, the impact of backpacks on posture is prone to undergo rapid changes. Failing to address the effects of backpacks on posture and spinal health in this phase could result in irreversible damage [10].

Various research on the influence of backpack weight on posture recommends that children and adolescents should not bear backpacks exceeding 10% of their body weight [7,11]. Backpacks weighing more than 10% of a child’s body weight can majorly impact their posture, potentially resulting in musculoskeletal pain and functional limitations [12,13]. Carrying backpacks that constitute 5% to 10% of body weight can cause negative postural compensations such as forward head posture, rounded shoulders, forward-leaning trunk, and increased lumbar lordosis, as well as detrimental spinal deformities [14].

Moreover, a rise in the weight of backpacks is typically linked to increased pain [12]. Consequently, parents and healthcare professionals must pay attention to the weight of backpacks, given their diverse impacts on spinal health under various loading conditions. Furthermore, there is a continuous rise in the prevalence of pain associated with spinal deformities [15]. The increasing occurrence of neck pain, forward tilt, rounded shoulders, and even lumbar vertebral damage due to overweight backpacks [16,17]. The prolonged use of overly heavy backpacks can cause skeletal muscle injuries, headaches, sleep disturbances, limb numbness, and various other health complications [18]. Medical experts believe that spinal pain is closely related to spinal posture [19].

Various biomechanical indicators are utilized to examine and appraise the well-being of spinal posture. For the neck and shoulder regions, the cervical vertebrae angle (CV angle) is instrumental in assessing the level of forward head posture [20,21]. Trunk and head angle measurements are utilized to evaluate biomechanical aspects of shoulders and neck when using backpacks [20]. Research indicates that heavy backpacks are blamed for lower back pain by more than 80% of students [22–25]. While subjective scales are common for back pain assessment, analyzing biomechanical indicators in young people can shed light on the underlying causes and mechanisms of back pain [26,27].

Therefore, this review explores the adverse effects of overweight backpacks through a comprehensive analysis of various indicators, aiming to propose improvement suggestions and enhance parents’ and healthcare professionals’ awareness of the risks associated with children and adolescents using backpacks. This review’s novelty lies in two key areas. Firstly, many existing reviews on this subject tend to be dispersed and lack a focused approach. This review, concentrating on the spine’s sagittal plane, aims to offer data valuable for backpack weight and design considerations [28]. Secondly, through the utilization of network meta-analysis, this review employs advanced analytical methods to compare multiple treatment approaches simultaneously. [29,30]. This method's strength is in quantifying and ranking various interventions by their effectiveness, guiding the choice of the best treatment strategy [31]. Through this advanced approach, we intend to transcend conventional reviews and present an extensive analysis of sagittal spinal deformities, enriching existing research in this domain.

2. Methods

2.1. Eligibility and exclusion criteria

The eligibility criteria of this review were: (1) Participants: children aged 6-18 years; only students utilizing backpacks are encompassed. Participant gender is unspecified. (2) Intervention: studies comparing backpack with no backpack usage are incorporated. Only conventional school backpacks are considered. (3) Outcome measures: the principal focus of this systematic review lies in the primary outcome measures within the sagittal plane of the spine, covering the cervical, thoracic, lumbar, and sacral regions. (4) Design of study: only controlled designed trials. (5) Others: Peer-reviewed and published in English, with a publication date before November 15th, 2023.

The exclusion criteria of this review were defined as (1) studies that focus on children with documented neurological disorders, spinal pathologies, and/or an inability to stand independently. (2) studies that investigate the effects of backpacks on the spine but are not specifically related to school-age children (e.g., "The effect of wearing high-heels and carrying a backpack on trunk biomechanics" [32]). (3) studies that exclude the impact of backpacks on the sagittal plane of the spine (e.g., "The impact of a school backpack's weight, carried on the back of 7-year-old students of both sexes, on the features of body posture in the frontal plane" [26]). (4) studies that compare the effect of straps or the design of backpacks. (5) studies that lack control.

2.2. Information sources

Three relevant authoritative databases (PubMed, Scopus, and Web of Science) were searched. References listed were scrutinized to identify grey literature that might be potentially eligible.

2.3. Search strategy

Two independent authors (M.J. and D.X.) screened the titles of all retrieved studies before the abstract screening. A third independent librarian (J.S.B) was invited to review synonyms and terms to improve sensitivity and specificity.

2.4. Study selection

Screening was performed on titles, abstracts, and full texts. Studies extracted from the databases were imported into EndNote 20 (Carlsbad, USA) for further screening and elimination of duplicates.

Two independent authors (M.J. and D.X.) screened all titles and abstracts before the search for inclusion and conducted further screening of the abstracts. A third independent author reviewed (Y.G.) the full texts of the studies that were selected before to determine the final studies that could be included in this systematic review.

2.5. Data collection process

The third author (J.S.B) conducted the collection and verification of data needed in the network meta-analysis independently. To ensure accuracy and thoroughness, an external reviewer was hired to verify the accumulated data.

2.6. Data items

To compare the overall effects of different intervention measures and ensure comprehensive and intuitive review details, the following information was collected and included in the extraction table.

The characteristics of the population involved the age range, average age, and gender ratio of the children included in each study. The intervention protocols and categorization encompassed the precise details of the interventions, including their content, as well as the timing and frequency at which they were administered. The review included the type of studies, such as randomized controlled trials, cohort studies, etc., as well as the duration of the study.

When conducting a network meta-analysis, data for each review was recorded on a separate extraction sheet. It included the sample size (N), mean, and standard deviation (SD) of each outcome at baseline and each recorded time point. These data underwent preprocessing for subsequent analysis. Data preprocessing was implemented to facilitate subsequent analysis.

2.7. Geometry of the network

The network geometry was made by the Aggregate Data Drug Information System (Version 1.16.8) to display the evidence structure. A node was assigned to each intervention, while the edges symbolized direct comparisons between intervention pairs, and the number on each edge represented the arms of the respective comparison.

2.8. Risk of bias within individual studies

The assessment of bias within individual studies employed the Cochrane Collaboration Risk of Bias Assessment Tool in the Cochrane Library Review Manager software (Version 5.3, Wiley, Chichester, United Kingdom), conducted independently by two authors (M.J. and D.X.) [33]. In cases of disagreement, an impartial arbitrator was engaged to resolve discrepancies, Cohen's kappa value was utilized to quantify the agreement between the authors.

If a study has no items with high risk or has fewer than 3 items with unclear risk, it will be considered to have a low overall risk. If a study has no item with a high risk but has more than three items with an unclear risk, it will be considered to have a moderate overall risk. Similarly, if a study has one item with a high risk, it also will be considered to have a moderate overall risk. Nevertheless, if a study has more than one item with a high risk, it will be considered to have a high overall risk.

The assessment of reporting bias involved the application of the Cochrane Collaboration Risk of Bias Assessment Tool. If a study has a pre-registered protocol number and all the outcomes in the protocol are fully matched with those reported in the article, it will be considered to have a low risk of selective reporting. On the other hand, if a study has a pre-registered protocol number but the outcomes reported in the article do not fully match those registered in the protocol, it will be considered to have a high risk of selective reporting. Lastly, if a study does not have a pre-registered protocol number, it will be considered to have an unclear risk of selective reporting [33].

2.9. Summary measures

In this systematic review, the effect size was reported as standardized mean differences (SMD) along with their standard errors (SE). The criteria provided by Cohen were used to interpret the magnitude of the effect size. According to Cohen's criteria, an SMD greater than 0.8 indicates a large effect size, an SMD between 0.5 and 0.8 indicates a moderate effect size, an SMD between 0.2 and 0.5 indicates a small effect size and an SMD less than 0.2 indicates a very small effect size [34].

The results of the analysis were presented in a rank probability plot under the consistency model. In this plot, the sum of all rank probabilities is 1. A lower rank number indicates a higher vertebral column bend, so interventions with lower ranks are associated with lower vertebral column bend. And present the results in the form of a ranking table [35]. This innovative method measures the dose-response effect of backpacks on the degree of vertebral column bend by comparing their rank probabilities.

2.10. Planned methods of analysis

Two independent authors (M.J. and D.X.) conducted data preprocessing and analysis. Microsoft Office Excel (Version 16.0) was employed to convert the original outcomes into standardized mean differences (SMDs) and their standard errors (SE). The ADDIS software (Aggregate Data Drug Information System, Version 1.16.8) was selected to conduct the network meta-analysis based on the Monte Carlo method.

2.11. Data pre-processing

Data pre-processing was conducted by two independent investigators using Microsoft Office Excel (Version 16.0). The original data was processed to convert all outcome measures into standardized mean differences for each recording time. Moreover, effect sizes for changes in overall sagittal vertebral column bend and alterations in individual indicators were calculated separately. The average standardized mean difference and its standard error were calculated using the following Equation (1) and Equation (2):

$$SMDave = 0.5 \times (SMD1 + SMD2) \tag{1}$$

$$SESMD = \sqrt{SMD12 + SMD22} \tag{2}$$

2.12. Assessment of inconsistency

Ensuring the coherence of evidence becomes paramount when closed loops are present in the intervention structure. In network meta-analysis, a technique employed to appraise inconsistency is the node-splitting analysis [36].

If the intervention structure does not have any closed loops or split nodes, or if the Bayesian p-value in every node-splitting analysis is greater than 0.05, or if the random-effects standard deviations are the same in both models, the consistency model will be used. However, if any of these conditions are not met, the inconsistency model will be applied [35].

2.13. Risk of bias across studies

Two independent authors (M.J. and D.X.) employed the Cochrane Collaboration Risk of Bias Assessment Tool to assess the risk of bias across the included studies [33].

2.14. Additional analyses

Using The Confidence in Network Meta-Analysis (CINeMA), the evaluation of confidence and assessment of reporting bias were conducted. According to the CINeMA tool, if the item "within-study bias" is considered a "Major concern" or if the other items are rated as "Some concern," the confidence level needs to be reduced by one level. If any of the other items are considered a "Major concern," the confidence level should be downgraded by two levels [37].

The "Average Risk of Bias" setting in CINeMA was used for summarizing risk of bias assessments. Studies directly comparing interventions were assigned scores of 1, 2, and 3 for low, moderate, and high risk of bias, respectively. These studies contributed 40%, 25%, and 35% to the total risk of bias assessment, respectively. To calculate the total risk of bias score, the percentage contributions were multiplied by their respective scores and summed up. In this example, the calculation would be $0.40 \times 1 + 0.25 \times 2 + 0.35 \times 3 = 1.95$. This value was rounded to 2, indicating "Some concerns" in terms of risk of bias.

3. Results

3.1. Study selection

A total of 244 titles and abstracts were generated during the initial search for screening 202 were retained for additional screening after 42 duplicate studies were removed. While screening records, 59 questionnaire surveys and 15 studies with incorrect participants were excluded. Consequently, 128 studies underwent full-text screening. Among the 128 studies that underwent full-text screening, 37 were excluded due to a lack of eligible comparisons. 62 were excluded due to ineligible interventions and 25 were excluded for having ineligible study designs. Following the screening process, four studies met the eligibility criteria and were consequently incorporated into the systematic review [38–41]. The flow diagram depicting this progression is featured in **Figure 1**.

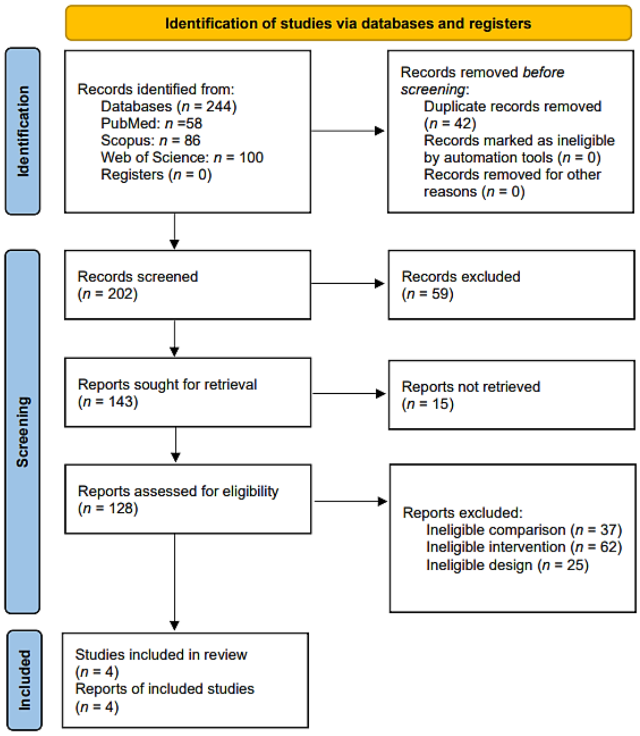

Figure 1. The PRISMA flow diagram of studies inclusion.

3.2. Study characteristics

According to the provided information, two studies included craniovertebral angle (CV angle) as outcomes, while four studies included various outcomes. One study covered all intervention categories, and the remaining studies encompassed two or three intervention categories. **Table 1** provided comprehensive details on all included studies, while **Figure 2** showcased the outcomes of the quality assessment conducted for these studies.

Table 1. Information of the included studies.

Study	Population	Age	Sex	Interventions				Outcome Measures	Main Findings
				Sex Ratio(F/M)	Loading	Detail	Category		
Cheung 2009 [38]	Students of 12 to 18 years	14.43	17 males and 13 Females	13/17	0 5%–10% 10%–20% 20%–30%	Standard backpack with 35-liter volume, no framing inside, no support, with padded adjustable shoulder straps on both sides, no compartments inside, no traps in waist or chest, or straps for load compression.	Control <10% 10%–20% ≥20%	CV angle (°)	(1) In participants with neck pain CV angles decreased when relative loading was 10% body weight ($P < 0.05$) (2) In participants without neck pain, CV angles decreased about 5 degrees when relative loading was 15% body weight ($P > 0.05$)

Table 1. (*Continued*).

Study	**Population**	**Age**	**Sex**	**Interventions**				**Outcome Measures**	**Main Findings**
				Sex Ratio(F/M)	**Loading**	**Detail**	**Category**		
Walicka-Cuprys 2015 [39]	109 children all aged seven years	7	51 males and 58 females	58/51	0 6.78%–10% 10%–17.47%	Carrying backpacks for an average of 50 minutes a day.	Control <10% 10%–20%	ThS (mm) THL (mm) LS (mm) KKP (deg.) TTI (deg.) SCR (deg.)	(1) Length of the spine: a significant difference between the>10% body weight loading group and <10% body weight loading group (*P* = 0.026) (2) A significant correlation between the loading of the backpack and the total length of the spine, lumbar lordosis, lumbar lordosis angle, and angle of sacrum inclination.
Brzęk 2017 [40]	155 children 7–9 years old (early school age)	7.6 ± 0.6	87 males and 68 females	68/87	0 24%–26%	Measuring the loading and the strap length of the school bag, as well as the parameters of body postures at the beginning of the school year and 10 to 11 months later.	Control >20%	Kyphosis angle (°) Lordosis angle (°)	(1) No significant differences in Kyphosis angle and Lordosis angle between early school-aged children with different sexes, ages, heights, or weights.
Vaghela 2019 [41]	A total of 160 participants are school-going children aged	10–15	89 males and 71 females	71/89	0 18%	Carrying backpacks with relative loading larger than 10% body weight.	Control 10%–20%	CV angle (°) CH angle (°) Sagittal Shoulder Posture (SSP)	(2) CV angle decreased significantly when carrying a backpack with a relative loading at 18% bodyweight (40.62 ± 10.16 vs. 36.16 ± 10.5 in stand posture with backpack and 33.86 ± 7.96 in dynamic posture with backpack). CH angle and SSP increased significantly when carrying a backpack with a relative loading at 18% body weight.

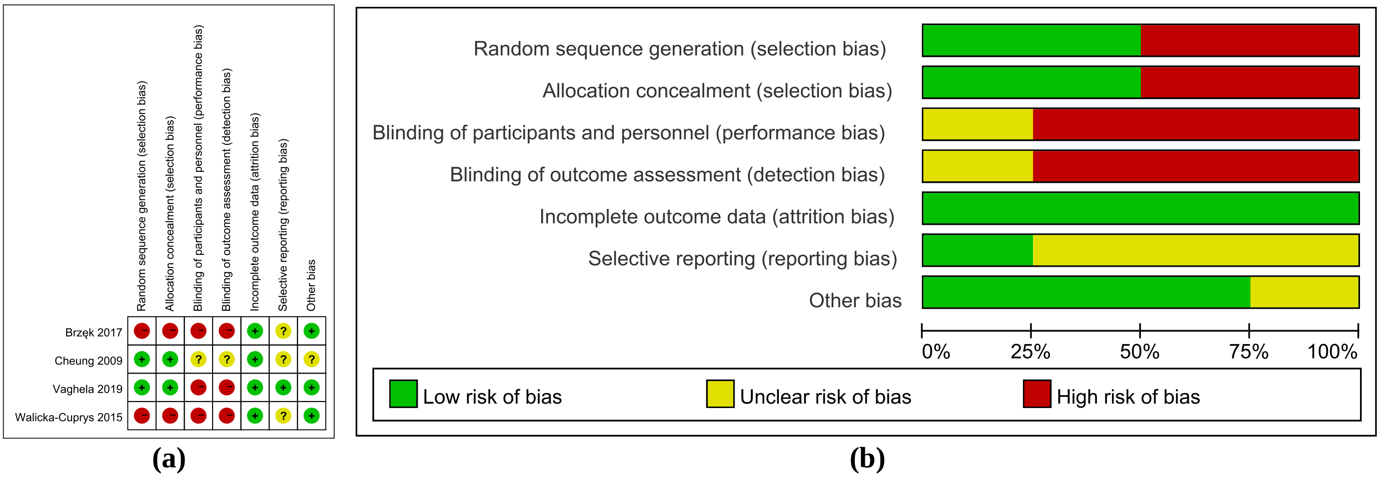

Figure 2. The risk of bias assessment. **(a)** Risk of bias summary; **(b)** Risk of bias graph.

3.3. Results of syntheses

3.3.1. Evidence structure

In the evidence structure represented by a network geometry (**Figure 3**), the following characteristics are illustrated. Each intervention is symbolized by a node, and the color of the node indicates the risk of bias linked to that intervention: (1) Red means a high risk of bias; (2) Yellow indicates an unclear risk of bias; (3) Green represents a low risk of bias. The size of individual nodes corresponds to the number of studies of each intervention in the net, in which larger nodes indicate greater sample sizes and smaller nodes indicate smaller sample sizes. The width of the lines connecting the interventions is the number of arms in each direct comparison. The specific number of arms in each comparison is indicated by the displayed numbers on the lines. The visual representations in the evidence structure contributed to providing a comprehensive overview of the risk of bias, sample sizes, and direct comparisons among different interventions.

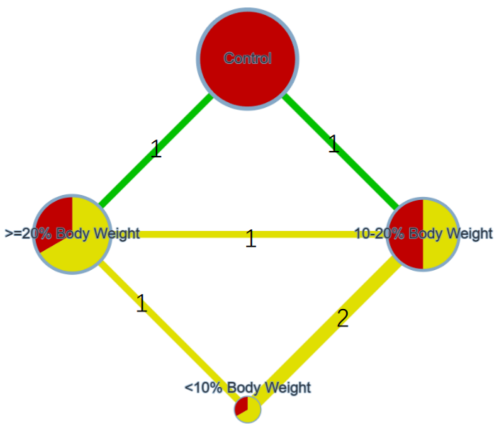

Figure 3. The network geometry of the interventions.

3.3.2 Network meta-analysis

According to **Table 2**, the random-effects standard deviation of consistency is determined to be 0.61 (95%CI: 0.12 to 1.90), and the random-effects standard deviation of the inconsistency model is 0.59 (95%CI: 0.12 to 1.90).

Table 2. Consistency and inconsistency evaluation and node splitting analysis.

Model test	Model	Random-effect standard deviation
	Consistency	0.61 (0.12, 1.90)
	Inconsistency	0.59 (0.12, 1.90)

Probability rankings for each intervention, with lower numbers indicating poorer sagittal plane indicators and higher numbers indicating better sagittal plane indicators, are provided in **Figure 4** and **Table 3**. The findings in **Table 3** indicated that when the bag's weight is less than 10% of body weight, it has the highest probability of causing a minimal negative impact on the spine within these three loadings (Probabilities in rank 1 = 0.57). When the bag's weight is more than 20% of body weight, it has the highest probability of making a maximum negative impact on the spine within these three loads (Probabilities in rank1 = 0.61). Furthermore, even when the backpack load is less than 10% of body weight, the sagittal plane biomechanical indicators do not show significant differences from those with higher loads. It still has the possibility of causing some degree of deformation, as the probability of less than 10% of body weight is 0.567.

Table 3. Ranking of measures and probabilities.

Intervention	Rank1	Rank2	Rank3	Rank4
Without Backpack	0.92	0.04	0.02	0.01
<10% of Body Weight	0.04	0.57	0.27	0.13
10%–20% of Body Weight	0.01	0.24	0.50	0.25
≥20% of Body Weight	0.03	0.16	0.21	0.61

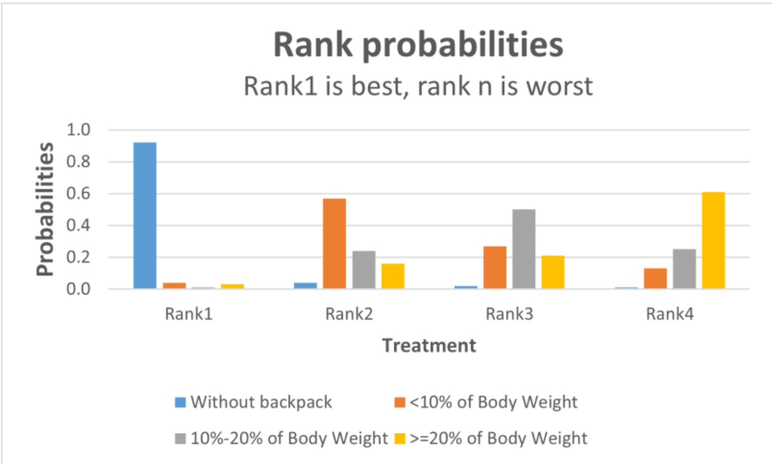

Figure 4. Ranking of measures and probabilities.

Table 4 is a league table of the network geometry that shows the weighted standard mean differences. The table values indicate column values relative to the row. For instance, 0.17 (–1.24 to 1.60) signifies the relationship between "<10% of Body Weight" and "10%–20% of Body Weight". Following Cohen's criteria: (1) SMD > 0.8 = large effect size; (2) SMD = 0.5~0.8 = moderate effect size; (3) SMD = 0.2~0.5

= small effect size; (4) SMD < 0.2 = very small effect size. Nevertheless, as all confidence intervals span the zero point, no significant difference is observed in pairwise comparisons.

Table 4. The league tables of the network geometry.

10%–20% of Body Weight	0.17 (–1.29,1.65)	–0.19 (–2.05,1.85)	2.01 (–0.11,4.15)
	<10% of Body Weight	–0.36 (–2.22,1.62)	1.83 (–0.87,4.37)
		≥20% of Body Weight	2.20 (–0.68,5.01)
			Without Backpack

Note: Mean (95% confidence intervals).

3.4. Reporting bias

Rereporting bias is depicted in **Figure 2**. If a study has no elements presenting a high risk or has fewer than 3 elements with unclear risk, it will be classified as having a low overall risk. If a study lacks items with high risk but includes more than three items with unclear risk, it will be designated as having a moderate overall risk. Similarly, if a study has one item with high risk, it will be also classified as having a moderate overall risk. Nonetheless, if a study has more than one item with high risk, it will be classified as having a high overall risk. According to **Figures 2** and **3** studies have a high overall risk, and 1 study has a moderate overall risk.

3.5. Certainty of evidence

The results of the confidence assessment conducted by CINeMA are presented in **Table 5**. In the table, "MC" indicates that the issue requires major concern, "SC" indicates that the issue requires some concern, and "NC" indicates that the issue requires no concern.

Table 5. Results of the confidence rating.

Comparison	Number of Studies	Within-Study bias	Reporting Bias	Indirectness	Imprecision	Heterogeneity	Incoherence	Confidence Rating
10%–20% of BW: <10% of BW	2	SC	SC	SC	MC	MC	NC	Very low
10%–20% of BW: ≥20% of BW	1	SC	SC	SC	MC	MC	NC	Very low
10%–20% of BW: Control	1	MC	NC	NC	MC	MC	MC	Very low
≥20% of BW: Control	1	MC	SC	NC	MC	MC	MC	Very low
<10% of BW: Control	1	MC	SC	NC	MC	MC	NC	Very low

Note: BW: body weight; MC: major concern; SC: some concern; NC: no concern.

4. Discussion

The purpose of this systematic review was to explore the sagittal vertebral column bend changes induced by backpacks in school-aged children and adolescents. The key outcomes of this systematic review and network meta-analysis are that, on one hand, a dose-response effect of backpack load is evident and analyzed using a unique probability method. A rise in backpack load is linked to a heightened bend in the sagittal plane of the vertebral column. Nonetheless, the degree of bending does not significantly vary among different loads, possibly attributed to the lower quality of the included studies. Consequently, when the backpack load is under 10% and between

10% and 20% of body weight, no notable improvement in sagittal plane vertebral column bending is observed compared to when it's 20% of body weight. The chance of detrimental spinal impact is not significant when backpack weight is under 10% of body weight or larger than 20% of body weight. There's a 0.61 probability of causing the most significant impact on the bend of the vertebral column.

It's indisputable that external loading would play an important role in affecting trunk kinematics. Research confirms that this impact is real and adheres to patterns. Both static and dynamic evaluations have shown that heightened backpack weight notably increases sway length and area, causing associated shifts in spinal biomechanics [42]. This paper includes longitudinal cohort studies that investigate the effects on children under both static and dynamic conditions, thereby offering insights into the impacts more closely aligned with real-world backpack usage. The American Occupational Therapy Association (AOTA) recommends that students should avoid carrying backpacks with loadings exceeding 15% of their body weight, this recommendation is correspondent with the result of this systematic review, which is that the threshold of loading of backpack might fall within the range from 10% to 20% of body weight. In 2012, this guideline was revised to 10% of body weight [43]. Research backing this opinion illustrates that with an average backpack load of 15% of body weight, there's an increase in anterior pelvic tilt and trunk inclination, as well as considerable vertebral column bending [44]. Even though this paper does not encompass studies on spinal lateral curvature and other coronal plane aspects, the weight thresholds causing significant effects remain consistent. Besides considering 15% of body weight as a crucial threshold for deformation, numerous studies indicate that the bending degree should correlate directly with the weight increase [45]. Consequently, the conclusions drawn in this article align with the results obtained in the study mentioned earlier. According to the rank probability-based findings, lighter loads may lead to smaller vertebral column bends, and heavier loads are more probable to cause larger bends. The option of not using a backpack, results in a positive correlation trend exists between the load and the sagittal plane bend in the vertebral column [46]. This finding is also supported by previous research. Findings suggest that backpacks can impact the posture and walking patterns of children and adolescents, with most changes linked to the backpack's weight [47]. Consequently, this article strengthens the assertion that the extent of vertebral column bending in the sagittal plane caused by backpacks is directly correlated with their weight.

Numerous biomechanical links exist between the use of backpacks and the biomechanics of the shoulder and neck areas. Research has indicated that a considerable number of students encounter pain in the shoulder and neck regions [48]. Moreover, evidence indicates that musculoskeletal pain in childhood and adolescence may pose a major risk for developing similar symptoms later in life [49]. Hence, this problem should not be underestimated. Earlier research frequently employed the craniovertebral (CV) angle, delineated by the intersection of a line from the seventh cervical vertebra and another from the external auditory meatus, to assess forward head posture and depict cervical vertebra biomechanics. Studies have demonstrated that when carrying a backpack, the CV angle reduces in response to heavier loads. Pronounced changes in the CV angle are seen when the backpack weight exceeds 15% of the individual's body weight [50]. The review mirrors this trend, though with certain distinctions. Backpacks undeniably cause a reduction in the CV angle, leading to cervical deformation and enhanced shear forces, potentially resulting in abnormal postures like forward head posture [51]. This review also encompasses indices related to cervical spine deformity and demonstrates a similar trend. However, this paper goes beyond merely focusing on a singular sagittal plane index from a single literature source. Instead, it comprehensively integrates all cervical indices included in the literature. Despite this approach, the conclusions remain consistent with those derived from individual indices in recent research, and the significance of 15% serves as a pivotal threshold. Furthermore, the studies referenced in this article reveal that backpacks can influence the normal development of the thoracic spine, thoracolumbar rotation, and the level of thoracic kyphosis. It might result in a forward shift in the central trunk posture. Excessive curvature of the thoracic spine can cause thoracic spine pain (TSP) and related musculoskeletal issues [52]. However, research on the thoracic spine is still limited, and the precise physiological mechanisms remain not fully comprehended. The problem of back pain is significant, affecting numerous adolescents and children. The incidence of back pain stands at 12.7%, most prevalent among children aged 7 to 10. Children with poor posture have a 2.5 times higher likelihood of experiencing back pain [53]. Lower back pain, mainly in the lumbar region, is likely linked to the lumbar spine [54]. According to the studies in this review, the difference in backpack weights impacted the alteration in abnormal body postures throughout an academic year. Notably, there was a decline in the anterior convex angle of the lumbar spine, its length, and the overall spinal length with increasing backpack load. Research also reveals that the cumulative microtrauma from carrying weight considerably raises pressure on the L3–L4 intervertebral disc, potentially leading to degeneration and lumbar spine syndrome [55]. It has also shown that in the sagittal plane, as the load increases, there is a notable bending of the lumbar spine's vertebral column. Consistent with the conclusions drawn in this study, an increase in backpack load results in a notable reduction in intervertebral disc compression at the T12-L1 to L4–L5 levels, diminished lumbar lordosis, and an escalation in reported pain. Hence, it is plausible that the intermediary mechanism behind the augmented lumbar deformity induced by added weight is likely an increase in intervertebral disc compression [56]. Several past studies have suggested that backpacks could lead to alterations in posture, and skeletal and muscle deformities, and might even cause a variety of health issues in children and adolescents [57–59]. This insight has increasingly formed the groundwork and impetus for more research. Additionally, numerous children and adolescents are already profoundly affected by back pain [60]. Investigations reveal that backpack weight affects trunk movement, spinal posture, and the activity of trunk muscles. Furthermore, modifications in trunk muscle activation and lumbar spine posture imply shifts in both the active and passive responses of soft tissues in the lower back. Nevertheless, additional research is required in future studies to explore the extent to which this significantly contributes to back pain [6,61].

In conclusion, this article's studies collectively summarize the bending of the vertebral column in the sagittal plane under backpack loading conditions, covering the cervical, thoracic, and lumbar spine. Previous research has explored the sagittal plane, but primarily in the contexts of shoulder strap design, particular sagittal plane areas, or other demographic groups [47,62–65]. Studies focusing exclusively on the entire sagittal plane concerning backpack weight are limited. Thus, this article adopts an innovative approach by examining the entire sagittal plane's indicators and standardizing outcome measures to encapsulate the effect of backpack weight on vertebral column bending, enhancing the understanding of spinal biomechanics. The study employs a distinctive probability comparison method to shed light on the dose-response impact of backpack weight on vertebral column bending in the sagittal plane. Moreover, this review offers an extensive understanding of how backpacks affect the health and posture of the sagittal plane, by encompassing the entire plane. This clarity enhances the understanding of backpack impacts on vertebral column bending in the sagittal plane during design, offering better scientific guidance for developing backpacks [66]. The recognition of backpacks' potential harm to the sagittal plane spurs this review to advocate for the innovation and use of advanced backpack technologies to tackle these concerns.

Despite providing valuable insights to some extent, this review has several limitations. One major limitation is the small number of articles included, only four, potentially not encompassing the full scope of research on vertebral column bending in the sagittal plane. Another limitation is that all articles were rated Very low in Confidence, suggesting limited study quality and evidence strength. Thus, the generalizability and reliability of this systematic review would be somewhat limited. The review did not delve into the design and positioning of backpacks concerning the sagittal plane [67–69], nor did it consider biomechanical indicators in dynamic conditions [42,70,71].

Furthermore, in the consistency model, statistical significance was not observed in either direct or indirect comparisons. It suggests that, despite identifying potential effectiveness rankings for different backpack loads, discerning the significantly superior intervention is unachievable. This limitation might thus diminish the review's practical utility. Furthermore, all direct comparison studies were single-arm studies, leading to each backpack weight being assessed in isolation, without cross-study comparisons. These limitations may significantly reduce the significance and reliability of the article's findings [72]. They could result in a limited inclusion of indicators, affecting the outcomes. Given these limitations, it is advised that future research adopts more robust study designs, like randomized controlled trials, to improve result reliability. Researchers are also advised to disclose all pertinent outcomes to reduce the potential for publication bias. Therefore, for parents and future researchers alike, while ensuring that the size and weight of the backpack are suitable for their back and shoulder strength, attention should also be paid to the design of the backpack to improve biomechanical indicators that are beneficial to children's health. Improving backpack design to reduce pressure on the neck and thoracic spine can also enhance sleep quality and reduce the likelihood of pain. In existing fields, adjustments such as modifying backpack width, implementing energy-saving mechanisms, and incorporating elastic shoulder straps have shown a certain degree of improvement in children's back pain and other biomechanical indicators. Additionally, to thoroughly evaluate the impacts of various interventions, including more direct comparison studies with sufficient sample sizes is essential.

5. Conclusion

This systematic review conducts a network meta-analysis to assess sagittal plane spinal vertebral column bending in children and adolescents from backpack loads. It reveals that increased backpack weight can bend the spinal column more in the sagittal plane. However, heavier backpacks don't always lead to greater spinal deformities due to the non-significant statistical nature of the findings.

This phenomenon may stem from disparities in the quality and publication timelines of the respective papers. Additionally, it could arise from the comparatively limited number of citations incorporated within this study, thereby resulting in an insignificance of its bibliometric impact differentials. This phenomenon may stem from disparities in the quality and publication timelines of the respective papers. Additionally, it could arise from the comparatively limited number of citations incorporated within this study, thereby resulting in an insignificance of its bibliometric impact differentials. The conclusions, limited by design flaws and publication bias, require cautious interpretation. Future research should include more studies, exploring different backpack designs, and investigating backpacks' mechanisms and effects in dynamic conditions.

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